DEVELOPMENT OF AN INTEGRATED TELEREHABILITATION INFORMATION MANAGEMENT SYSTEM TO SUPPORT REMOTE WHEELCHAIR PRESCRIPTION

by

Andi Saptono

Bachelor of Science, Bandung Institute of Technology, 2000

Master of Science, University of Pittsburgh, 2005

Submitted to the Graduate Faculty of

Health and Rehabilitation Science in partial fulfillment

of the requirements for the degree of

PhD in Rehabilitation Science

University of Pittsburgh

2011

UNIVERSITY OF PITTSBURGH
HEALTH AND REHABILITATION SCIENCES

This dissertation was presented

by

Andi Saptono

It was defended on

April 11, 2011

and approved by

David M. Brienza, PhD, Professor

Michael McCue, PhD, Professor

Valerie Monaco, PhD, MHCI

Dissertation Advisor: Bambang Parmanto, PhD, Associate Professor

ABSTRACT

DEVELOPMENT OF AN INTEGRATED TELEREHABILITATION INFORMATION MANAGEMENT SYSTEM TO SUPPORT REMOTE WHEELCHAIR PRESCRIPTION

Andi Saptono, PhD

University of Pittsburgh, 2011

Information technology (IT) is central in providing Telerehabilitation (TR), which enables people with disabilities access to limited number of qualified practitioners with specialty expertise, especially at rural areas. Prior to 2008, most TR utilized non-integrated IT systems to provide its basic infrastructure. Using this approach, data management has to be done manually over multiple non-integrated systems, increasing the possibility of outdated or missing data. An integrated system that is open, flexible, extensible, and cost-effective was designed and developed as a solution to mitigate this problem. The work described in this dissertation elaborates the process of developing such system, called the Versatile and Integrated System for Telerehabilitation (VISYTER). VISYTER was intended to become a platform that is capable of delivering any TR, and was first used to support Remote Wheelchair Prescription (RWP), a TR

effort to support clinicians in rural Pennsylvania to prescribe wheeled mobility and seating devices.

The development process of VISYTER consisted of three main phases: identification and verification of requirements, validation, and evaluation. The requirement identification and verification phase involved a group of expert clinicians from RWP with the purpose of identifying the requirement of the system to support RWP: a system that can provide real-time teleconsultation and documentation support for prescribing a wheeled mobility intervention. Validation studies were conducted with help from ten individuals, including physicians, clinicians, and suppliers participated to validate VISYTER in their workplaces. All participants agreed that VISYTER can be used to properly support both the teleconsultation and documentation phase of RWP. Afterward, the usability of VISYTER was evaluated through a comparison study with a commonly utilized videoconferencing system in TR, POLYCOM. Twenty-six clinicians participated in a counterbalanced experimental study to measure the difference in usability for completing client assessment tasks using both systems. The study found VISYTER to be more efficient and less prone to error when compared to POLYCOM. Based on these findings, the study concluded that an integrated system could improve the usability TR delivery when compared to non-integrated systems approach.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

First of all, I would like to thank God for the opportunity and the support that He has provided for me. Without His constant help, I would never be where I am right now.

I am truly indebted to my advisor, Dr. Bambang Parmanto, who has not only been my advisor, but also my second father in Pittsburgh. I will always remember the support and guidance that helped polished my skill, both in academy and professional life, through my graduate study at Pitt. I am honored and humbled to be able to work together with a wonderful person such as Dr. Parmanto. Thank you.

I would like to thank my dissertation committee, Dr. David Brienza, Dr. Michael McCue, and Dr. Valerie Monaco for your guidance and support over the past few years. Thank you for all the efforts and time that you have spent to support my work in the field of Telerehabilitation. Special thanks to Dr. Richard M. Schein and Dr. Mark Schmeler for providing the opportunity to learn more about rehabilitation services. To Rich, your help, friendship, and encouragement mean a lot to me.

I would also like to thank all the faculty, staff, and students whom I have met during my time within the Health Information Management department, especially my team, the Health and Rehabilitation Informatics group ("HARI Group") that stood by my side and supported me to make Telerehabilitation a reality. Specifically, I would like to thank Gede Pramana, Wayan Pulantara, Reina Wang, and Solehudin Ayubi for being both my friends and my team mates. Mere words cannot express my gratitude towards you all, for without you, I would never be able to finish any of these works. To Dr. Richard M. Schein (again!) and Jamie Schutte, thank you for thoroughly reading the draft of this dissertation. I cannot even count the many times I asked you to read it over and over again, just to revise a single paragraph.

Last, but not least, I would like to thank for the continued love from my family, both in Indonesia and in Pittsburgh. Thank you so much, dad and mom, for allowing me to come here to

Pittsburgh, far away from home to finish my study. Thank you to the Indonesian Community in Pittsburgh for welcoming and making my stay in Pittsburgh a special moment in my life.

This study is supported by RERC on Telerehabilitation, funded by NIDRR Department of Education, Washington DC, Grant # H133E090002.

1.0 INTRODUCTION

1.1 DEFINITION OF TELEREHABILITATION

The term 'Telerehabilitation' was first coined by Katherine Seelman in 1996 (Seelman, 1996). In its inception, Telerehabilitation (TR) was perceived as a complement to telemedicine and a response to the service delivery gap resulting from the shortened in-patient rehabilitation service. Professional organizations such as the American Speech-Language and Hearing Association (ASHA), American Occupational Therapy Association (AOTA), and American Physical Therapy Association (APTA) offer different definitions of TR based on their individualized visions. For example, AOTA defined TR as the clinical application of consultative, preventative, diagnostic, and therapeutic services via two-way interactive telecommunication technology (Wakeford, Wittman, White, & Schmeler, 2005).

TR has also been defined as the application of telecommunication technology for supporting rehabilitation services (Russel, 2007) and the application of telecommunication technology that provides distant support, assessment, and intervention services to individuals with disabilities (Ricker, 2002).The field of TR exists under the assumption that the barrier of distance can be minimized to enhance access that will open new possibilities for delivering intervention strategies across the continuum of care (Winters, 2002). TR has also been discussed as a way to improve access to assistive technology services for people with disabilities in underserved areas (Cooper et al., 2001).

Based on these definitions, three facts can be summarized about TR. First, TR is not a new service in the field of health, but a different model of rehabilitation service delivery, which aims to enable individuals with disabilities or to restore individuals' impairments. Second, TR may deliver a wide range of services, from consultative, preventative, diagnostic, assessment, intervention, therapeutic, and support for clients. Third, TR may deliver rehabilitation service in both clinical and home settings.

In the Rehabilitation Engineering Research Center on Telerehabilitation (RERCTR), these characteristics were used to create a long definition of TR: the application of telecommunication networks and the Internet to deliver consultative, preventative, diagnostic, and therapeutic services to enable individuals with disabilities and to restore individuals' physical and psychosocial functions, in clinical, home, work, and community setting (Parmanto & Saptono, 2009).

1.2 SIGNIFICANCE OF TELEREHABILITATION

TR offers opportunities for providing equitable access to underserved areas such as rural communities to advanced rehabilitation services that are otherwise only available in metropolitan areas. TR also has potential to allow rural community clinics to expand their services to include specialized service, such as speech-language pathology and wheelchair assessment services. Utilizing the Internet as a platform also has the potential to bring an efficient and cost-effective solution to the growing demands of interconnectivity and scalability in modern healthcare service.

1.2.1 Delivering Rehabilitation Service in Limited Resource Areas

The delivery of services in remote areas is often hampered by the limited expertise in specialized areas of rehabilitation (Callas, Ricci, & Caputo, 2000). In addition, providers in remote areas may also have limited technical resources. These limitations often require remote area clinics to make referrals to the metropolitan clinics, which forces individuals to travel from their home to the metropolitan clinics. However, mobility and accessibility restrictions may limit individuals from traveling and receiving healthcare service in urban areas (Hatzakis, Haselkorn, Williams, Turner, & Nichol, 2003). Individuals with sensation issues may also develop secondary issues due to the prolonged sitting during travel (Sabharwal, Mezaros, & Duafenbach, 2001). Overall, the limitations in expertise and technical resources are often pointed to as the reason of the decreased quality of healthcare in remote areas.

TR provides a solution to bridge the gap between individuals with specialized rehabilitation needs living in remote areas and the source of specialty care, which often times resides in metropolitan areas (Heinzelmann, Lugn, & Kvedar, 2005). Through TR, rehabilitation providers in remote areas may provide more specialized services by remotely connecting with their counterparts in metropolitan area centers. This process may also provide indirect educational benefits for participating remote area clinicians, which further helps mitigate the challenge of limited expertise in remote areas. In time, TR may improve rehabilitation service quality and stability in regions with limited expertise and technical resources (Krupinski et al., 2002).

1.2.2 Cost-effective Rehabilitation Service

Limited expertise on specialized rehabilitation service and technical resources may require individuals to travel long distances to receive an assessment, a specific treatment, or both to address their needs. Studies with veterans have revealed that individuals travel more than 25 miles for appropriate healthcare (Randal, Kilpatrick, Pendergast, Jones, & Vogel, 1987; Wollinksky, Coe, Mosely, & Homan, 1985). Recent study in the RERCTR also revealed that individuals in rural Pennsylvania have to travel in average 3 hours over 200 miles to arrive in metropolitan centers to receive their seating and wheeled mobility assessment (Schein, 2009).

TR provides a cost-effective solution to minimize the barrier of distance between clinicians, researcher, and individuals that require specialized services. For example, by connecting the rural and metropolitan clinics, TR effectively decreased the travel between rural communities and specialized metropolitan centers for both clinicians and individuals living in rural areas. For clinicians, the time originally lost in travel may be used to serve more individuals, creating a more efficient service (McCue & Palsbo, 2006). Allowing clinicians to continuously be in touch with individuals with specialized needs may also result in cost-saving from preventing secondary conditions. This solution is also beneficial in metropolitan areas where individuals have limited travel options, due to either traffic or personal condition.

The high penetration of broadband connections among Internet users in the United States, estimated to reach 80% (Madden, 2006), provides a cost-effective platform to deliver even the most demanding services such as real-time videoconferencing to remote areas. Figure 1 depicts the potential cost-saving of conducting TR over the Internet when compared with traditional face-to-face rehabilitation service. In the beginning, TR will require a certain amount of set-up cost, which is generally used to buy the equipments, prepare the sites, and conduct training to perform the service in a 'tele' setting. In time, the set-up cost will be compensated by the lower cost of conducting the rehabilitation service remotely.

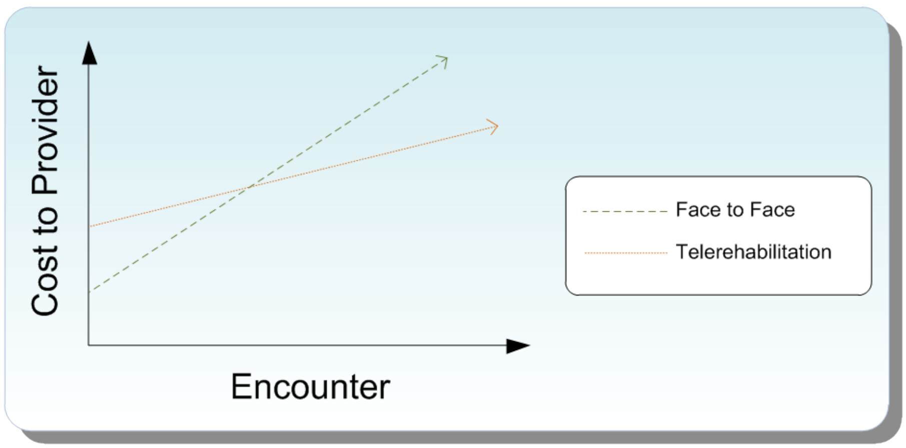

Figure 1 Cost Comparison Diagram

1.2.3 New Approach to Deliver Rehabilitation Service

Delivering specialized service for individuals with cognitive disabilities requires the service to be available anywhere and anytime. Individuals with cognitive disabilities may experience functional limitations that impact their ability to perform effectively in their daily life. For example, individuals may not be able to properly recall the steps to successfully perform activities of daily living, such as cooking a meal. Even with extensive vocational training, persons with cognitive disabilities may need a mentor to constantly monitor their activities to ensure that their tasks are done properly.

TR provides an advantage over traditional face-to-face encounters in specialized service that requires constant monitoring of individuals. The use of TR enables clinicians to remotely monitor individuals during their daily activities. The service provided through TR allows individuals to receive constant support for overcoming obstacles to successfully complete their tasks, anywhere, anytime. For example, in the RERCTR, a model has been developed to create a TR-based "in vivo" supports for individuals with cognitive disabilities by introducing non-invasive wearable equipment (http://www.rerctr.pitt.edu). The result is a mechanism that prompts clients to correctly complete tasks, even when no clinicians or mentors are available on-site.

1.3 INFORMATION TECHNOLOGY FOR TELEREHABILITATION

Minimizing the barrier of distance can be accomplished through several telecommunication modes. Face-to-face interaction between clinicians and their clients can be conducted through videoconferencing systems. Presentation of stimuli or testing materials can be delivered inside web browsers. Information technology (IT) is central to TR in delivering the services to its recipients (Bashshur, Shannon, Sapci, 2005).

1.3.1 Challenges of Current Information Technology in Telerehabilitation

Most TR utilized readily available systems and technologies to facilitate face-to-face interactions between clinicians and clients in remote setting. For example, several TR used popular, high-end videoconferencing systems such as POLYCOM to provide audio and video communication between clinicians and clients. The use of these videoconferencing systems in TR can be seen in several studies, such as in Malagodi et al. (1998), which compared the use of these videoconferencing systems to connect sites through plain-old-telephone-system (POTS) lines and Integrated Services Digital Network (ISDN) lines to complete seating and mobility assessments, and in Savard et al. (2003), which presented the use of these videoconferencing systems to deliver neurologic-related consultations to individuals living in remote areas.

Although most readily available systems and technologies can be deployed quickly and ready to use out of the box, these systems are not customized toward the requirements of healthcare or TR (Rosen, Lauderdale, & Winters, 2002). In most cases, only a small portion of tasks in TR can be supported by a single system. As the result, each specific TR task has to be completed using different, 'sub-optimal' systems (Winters, Feng, Wang, Johnson, & Foil, 2002). Most TR required the use of multiple systems to provide the proper interactions between clinicians and their clients. For example, desktop computers may be used alongside the videoconferencing system to run data collection systems or electronic health record system (EHR) which records the result of the rehabilitation service.

The use of multiple systems presented two major challenges in a complex TR. First, the use of several different systems increased the burden of a clinician during a TR session. The previous example portrayed clearly of this challenge: clinician would need to simultaneously use a high-end videoconferencing system to perform teleconsultation and a desktop computer running both a data collection system and EHR to record the outcome of the service.

The second challenge was inconsistent and fractured information spread across multiple systems. Most readily available systems were designed to be close, self-contained systems. Any information recorded inside one system cannot be transferred easily to other system, unless clinician manually accessed each system to add, retrieve, copy, or modify the information. This approach may lead to errors, misplaced or lost information, which would lead to reduction in information integrity and security due to inconsistent and fractured information stored in many systems. Furthermore, inconsistent and fractured information may also create a fracture in the clinician’s workflow (due to the delay from accessing proper information in time), thus further reducing the efficiency of TR.

Winters, Feng, Wang, Johnson, and Foil (2004) proposed the development of interfaces that functions as information bridges between multiple systems to solve the fractured information flow. For example, an information bridge can be developed to allow access of information between a pedometer and a desktop computer running an email system. This bridge would allow a client to send the data from the pedometer to the EHR. Another interface would be developed to bridge the same pedometer with videoconferencing system. This bridge would allow the data from the pedometer to be accessible during a real-time videoconferencing session. The use of information bridges between multiple systems in TR is illustrated in Figure 2a.

The implementation of the bridge faced two major barriers. The first barrier was the number of the bridges to be developed. In complex TR, the number of the bridges would grow exponentially in accordance with the number of systems used to deliver the service (Figure 2b).

Adding a new system into complex TR would require extensive amount of development effort to build all bridges connecting the new system to the existing ones. The second barrier was the closed nature of the systems. As previously mentioned, these systems were designed to be close, self-contained systems. Modifying these systems to implement the bridges required specific expertise and a lot of efforts, which may drive the cost of set up and sustaining TR in the long run. In some cases, modifying the system was almost impossible.

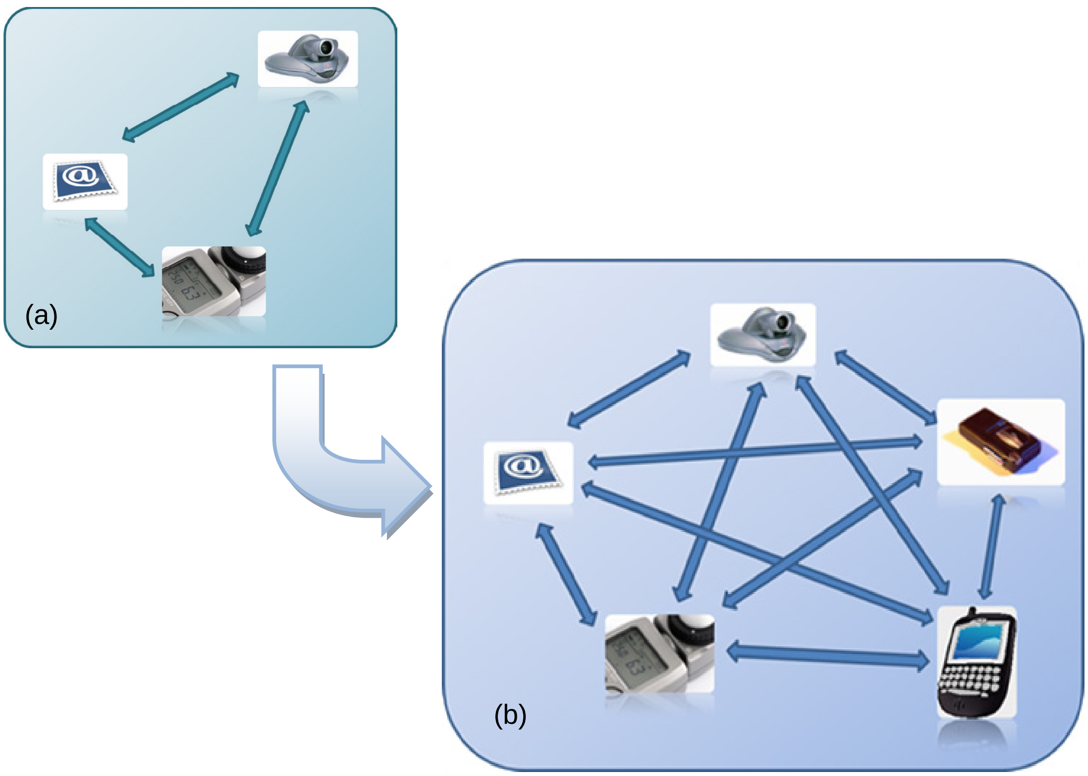

Figure 2 Exponential Growth of Bridges

The use of the bridges also did not completely address the two major challenges to TR. First, the information was fractured. Although the bridges provided ease of access to information, the information itself was still stored across multiple systems. Second, clinicians of a complex TR would still be required to control multiple systems and access multiple bridges. Looking back to our previous example, the clinician would still be required to control the videoconferencing system and a desktop computer to access the EHR. In addition, the clinician would be required to control the bridge to access the information stored in client's pedometer. These barriers made the information bridge almost impractical to use in TR.

1.3.2 Information Technology Solution for Telerehabilitation

Integration of systems has been viewed as a possible solution to mitigate the fractured information flow, and also improve the system's ease of use. With an integrated system, TR practitioners, including clinicians, would only need to utilize a single system as opposed to multiple systems in traditional TR. In addition, an integrated system can potentially streamline all information exchange within TR by seamlessly manage any information exchange between all systems used to deliver TR. As a result, the overall usability of TR could be improved (Winters, 2002).

An information management system would be required to provide the infrastructure to build the integrated system. This system will be responsible for managing the flow of information and data across any technologies and systems used to deliver TR. With the use of an information management system as the center of the integrated system, the information bridge concept can be simplified. In place of developing multiple information bridges that connect all the technologies and systems in TR, only a single bridge would be required to connect between each technologies or systems used to deliver TR with the information management system. As the result, the number of bridges can be reduced (figure 3). This approach also has the advantage of scalability, in which new technologies can be added into the system easily. In the RERCTR, the methodology to build this integrated system is called the PITT model. Chapter 3 provided a more in depth discussion on the PITT model and its implications for TR.

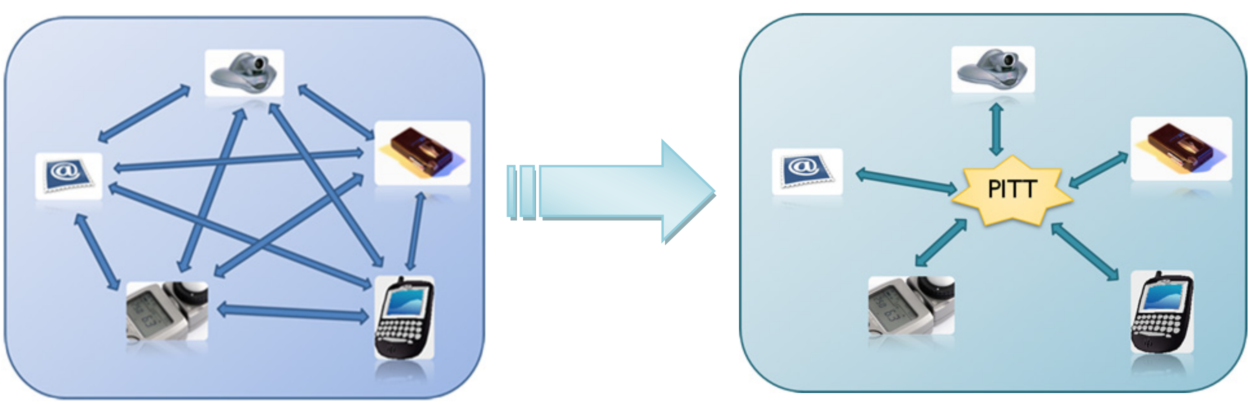

Figure 3 Integration of System

To support TR efficiently, the integrated system had to meet the requirements and the natural flow of information in TR (Brennan & Barker, 2008). The use of closed, non-integrated IT systems to support TR prohibited any flow of information, thus was incompatible with the integrated system. At the RERCTR, in place of the non-integrated IT systems, technologies that were open to integration through the use of standardized information exchange protocols were utilized as components for the integrated system. For example, in place of high-end videoconferencing systems, such as POLYCOM, a combination of USB-based web cameras and open-source videoconferencing software was used to support real-time interactivities between clinicians and their clients. These technologies have two advantages over non-integrated IT systems: lower cost of procurement, and ease of customization.

1.4 RESEARCH QUESTIONS

Integrated system appeared to be an appropriate solution to challenges faced by the use of multiple systems in TR. First, integrated system has the potential to solve the fractured information flow through the use of a centralized information management system. Second, integrated system has the potential to improve the ease of use of TR system by requiring TR practitioners to interact with only a single system in place of multiple systems. Overall, the use of integrated system has the potential to improve TR system's usability.

This dissertation concentrates on presenting the development work and the usability assessment process of an integrated system to support TR. This integrated system has been used in several TR projects within RERCTR, including remote wheelchair prescription and telemonitoring for speech-language therapy. In this dissertation, remote wheelchair prescription is used as the example of the TR supported by the integrated system.

The development of the integrated system utilized the methodology described in the PITT model, followed by a formative and a summative usability study. The formative usability assessment was conducted during the development of the system to ensure that the system was able to meet all TR requirements (including high clarity of video/audio, no fractured information, and seamless integration between all components). This study utilized a participatory study design with the help from a group of TR clinicians from multiple rural sites across Pennsylvania. After completing the system, a summative usability assessment was conducted to evaluate the integrated system by comparing the use of the integrated system with non-integrated systems to deliver TR.

1.4.1 Specific Aim 1: Develop an Integrated System to Support Telerehabilitation

The work described in this dissertation started with the development of the integrated system. This work follows a standardized spiral prototyping method for software development. The goals of the development process were to:

- Identify the requirements of TR
- Identify IT components to build the integrated system according to the requirements of TR
- Create a platform that integrates all the IT components
- Integrate all components into the platform to make a single, integrated system to support TR

1.4.2 Specific Aim 2: Assess the usability of the integrated system in supporting TR

During the formative usability assessment, the questions to answer were:

- Does the system provide the support to conduct TR according to the requirements?
- Do the features provided within the system hinder users from completing tasks?
- According to the user, what are the strengths and the weaknesses of the system?
- What kinds of additional features (beyond the original requirements) are required to further support the user?

1.4.3 Specific Aim 3: Evaluate the usability of the integrated system vs. the multiple systems to deliver TR

The usability of the systems is measured through four aspects: the ability of the system to support users in completing their tasks (effectiveness), the amount of effort required by users to complete tasks (efficiency), the ability of the system to help users recover from error (error recovery), and the ability of the system to satisfy users' expectation (satisfactory). During the formative usability assessment, the questions to answer are:

- Does the use of the integrated system allow users to complete their tasks more effectively compared to the non-integrated systems?
- Does the use of the integrated system allow users to complete their tasks more efficiently compared to the non-integrated systems?
- Which approach provides the easiest way for the user to solve problems encountered during use?
- Which approach is perceived to satisfy the user's expectation?

1.5 DISSERTATION OUTLINE

Chapter 2 provides a background review of works relating to TR. The first part examines the evolution of the field of TR from Telemedicine and Telehealth, including the current state of the arts in TR. Next, the technologies used in current TR are detailed. Finally, the last part explores the challenges that these technologies encounter in daily practice, and presents the integrated system as a solution to translate these technologies properly.

Chapter 3 describes the PITT Model, a novel methodology to develop an integrated system for supporting TR by creating a centralized platform that connects all IT components. This chapter explains the evolution of the common methodology for system development into a methodology that ensures not only an efficient and effective system, but also a system that complies with the requirements of TR. This chapter also elaborates on the impact of the PITT model on TR.

Chapter 4 presents the initial works to implement the PITT model in the Remote Wheelchair Prescription project (RWP). This chapter describes the process of requirements identification, technology identification, and matching the technology to the requirements.

Chapter 5 details the step-by-step development of an integrated system to support TR, called the Versatile and Integrated System for Telerehabilitation (VISYTER). This chapter provides a detailed report on how the PITT model was used to guide the design, development, and deployment of the system. The chapter also describes the process to modify VISYTER for RWP.

Chapter 6 reports the result of the formative usability assessment conducted to refine VISYTER for RWP. Although the works described in this chapter focus on the usability of VISYTER for RWP, the method of conducting usability assessment is applicable in any TR projects/applications.

Chapter 7 investigates the results of the summative usability evaluation of the use of VISYTER compared to non-integrated systems to deliver RWP. The study utilizes Post-Study System Usability Questionnaire (PSSUQ), a standardized usability measurement tool developed by International Business Machines (IBM).

Chapter 8 summarizes the studies and provides further insight into the future impacts of the approach described for the field of TR. Also included are discussions of the previous chapters and investigations into the directions of potential future research and developments in TR.

Figure 4 depicts the roadmap of interrelationship between the researches involved in the current work.

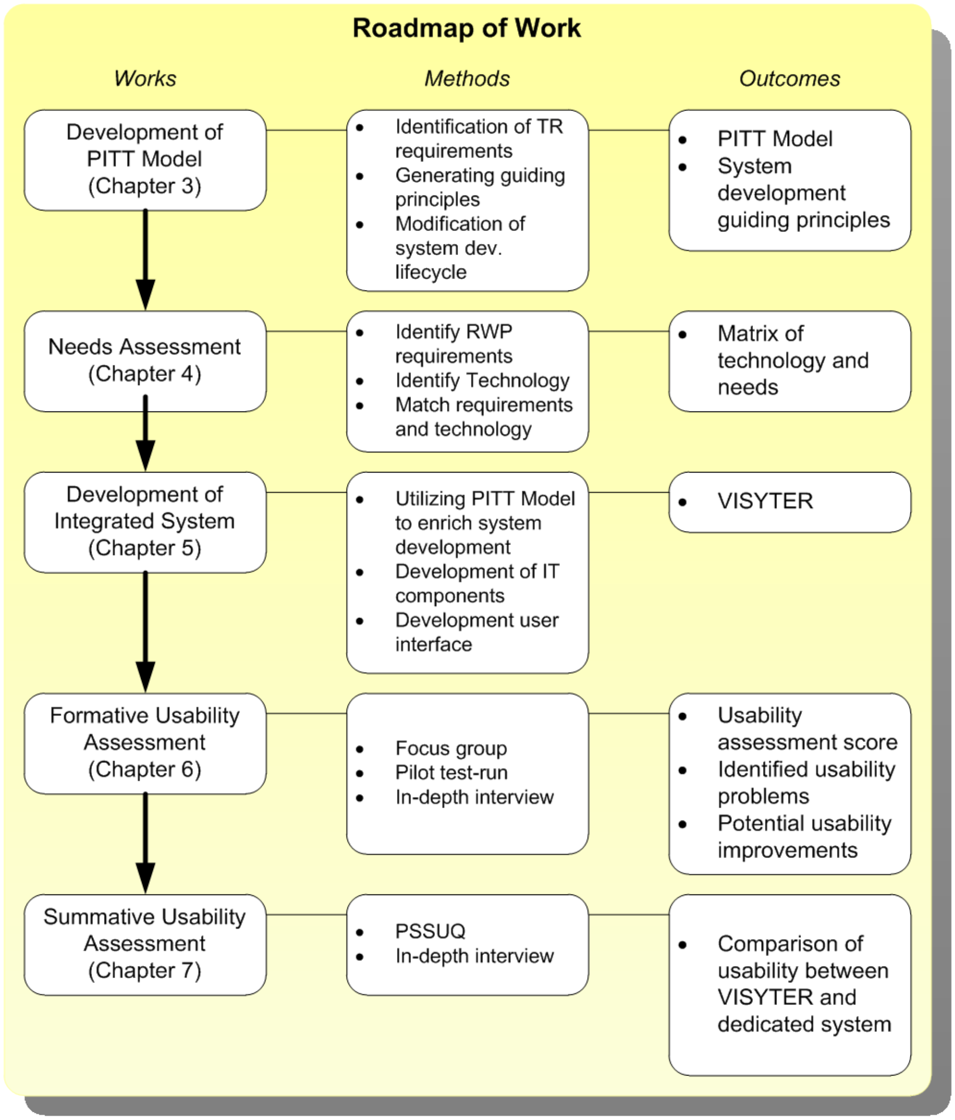

Figure 4 Roadmap of Work

2.0 BACKGROUND

2.1 FROM TELEHEALTHCARE TO TELEREHABILITATION

The introduction of advanced telecommunication technologies into healthcare has initiated new possibilities of delivering quality of service over distance. Telemedicine, for example, is one of the oldest areas of applied telecommunication technology in medicine. In telemedicine, electronic medical information is exchanged between healthcare sites through electronic telecommunication networks to improve patients' health status. Telehealthcare is another area where telecommunication technology is used to improve healthcare service. In general, telehealthcare is the use of electronic information and telecommunication technologies to support the management of care, including long-distance clinical care, healthcare-related education, and healthcare administration.

Telerehabilitation (TR) was once considered to fall under both telemedicine as a part of the delivery of clinical services, and telehealthcare as a part of care management for individuals with disability or chronic health condition (Winters, 2002b). Even though substantial differences exist on the use of telecommunication technologies in many rehabilitative practices, such as in audiology/speech-language pathology and neuropsychology, the term 'Telerehabilitation' is not commonly adopted to describe the service. Instead, field-specific terms, such as 'tele-PT', 'telepresence', 'tele-neuropsychology', or 'tele-SLP' are used to describe the rehabilitation service. However, the underlying concepts of these terms are the same: delivering rehabilitation service over distance through the use of telecommunication technologies. This concept differentiates TR with Telemedicine, which focuses on restoring patients’ health through medical treatments.

Two major factors prompted the rapid growth of TR. The first is the availability of advanced Internet technologies in most homes and workplaces via cost-effective broadband connections. These technologies have the potential to enable the delivery of TR services that were previously too expensive to have in the home, work, and community settings. The second factor is the growing need of rehabilitation for individuals in their natural settings. Currently, the advancement of techniques in medical treatments has allowed individuals to survive fatal accidents/traumatic episodes in their life. These individuals who many are now living with multiple disabilities require constant support for successful community integration. TR has the potential to provide such support remotely, allowing individuals to receive rehabilitative service anywhere-anytime. For example, individuals with traumatic brain injury may receive periodical reminders from their counselors to guide them in accomplishing their daily tasks in their workplace environment (Gentry, Wallace, Kvarfordt, & Lynch, 2008).

2.2 CURRENT STATE OF RESEARCH IN TELEREHABILITATION

In 2002, Jack Winters proposed four conceptual models of TR delivery: teleconsultation, telehomecare, telemonitoring, and teletherapy.

- **Teleconsultation.** Teleconsultation is defined as a standard "face-to-face" TR model using interactive videoconferencing between a local provider (and client) and a remote rehabilitation expert to gain access to specialized expertise. This model is generally used to connect clinician (and client) and experts at a distant location to gain access to specialized expertise (Lemaire, Necsulescu, & Greene, 2006; Iwatsuki, Fujita, Maeno, & Matsuya, 2004).
- **Telehomecare.** Telehomecare is defined as service delivery where a clinician (usually a nurse or technician) coordinate a rehabilitation service delivery from various providers to client's natural environment, which generally includes home and work settings. Currently, telehomecare has gained more momentum due to the aging population and the need to deliver rehabilitation service at client's home (Demiris, Shigaki, & Schopp, 2005; Sanford et al., 2006; Giansanti, Morelli, Maccioni, & Macellari, 2007; Huijgen et al., 2008).
- **Telemonitoring.** Telemonitoring is the clinical application where the rehabilitation provider sets up unobtrusive monitoring or assessment technology for the client. Some telemonitoring approach utilizes technologies (such as haptic technology and virtual

reality) that provide real-time feedback to both clinician and client, allowing a limited degree of interactivity between the client and the provider. The application of this model ranges from simple monitoring through a low-bandwidth network to immersive virtual-reality monitoring in a real-time setting (Russel, 2007; Giansanti & Maccioni, 2008).

- **Teletherapy.** Arguably the focus of most TR, teletherapy is defined as a model of TR delivery where a client conducts therapeutic activities (play or exercise) at home/rural clinical setting. The therapy itself can be done synchronously or asynchronously. Teletherapy is adopted in many clinical applications, such as teleneuro/orthopedic-rehabilitation (Feng & Winters, 2007; Placidi, 2007), teleaudiology/tele-SLP (Hill & Theodoros, 2006; Theodoros, 2008) and postsurgical teletraining (Heuser et al., 2007).

To explore the current state of research in TR, a search through Medline (PubMed) database was conducted. The search used the following keywords: telerehabilitation, telemonitoring, telehomecare, teleconsultation, teletherapy, and telehealth. Aside from the keyword 'telerehabilitation', these keywords can be used by any paper, some of which were not necessary related to TR. For example, a simple search with ‘teleconsultation’ as the keyword resulted in 2,069 papers retrieved from PubMed database. Therefore, filter keyword 'rehabilitation' was added to achieve better precision of the query for the search.

The number of papers retrieved using those keywords were as follows: telerehabilitation (93), teleconsultation and rehabilitation (129), telehomecare and rehabilitation (5), telemonitoring and rehabilitation (37), teletherapy and rehabilitation (4), telehealth and rehabilitation (74). Field specific keywords, such as 'teleSLP', 'telePT', 'teleophtalmology', and 'teleneuropsychology' were also used to query the database; however, the search results for these keywords were already included in the broader keywords. Next, the results were refined by reviewing the papers’ abstracts and including only papers that relate to rehabilitation services. Furthermore, the content of the papers were evaluated to reclassify the papers into more accurate TR service categories. The result was 238 papers related to TR as per the categories presented in Table 1.

Table 1 Papers in Telerehabilitation

Categories	Number of Papers	Prototypical example
Teleconsultation	61	Brennan, Georgeadis, Baron, & Barker, 2004
Telemonitoring	36	Piette et al., 2008
Telehomecare	36	Hoenig et al., 2006
Teletherapy	60	Sugarman, Dayan, Weisel-Eichler, & Tiran, 2006
Telerehabilitation Service: Other	45	

2.2.1 Teleconsultation

Of the 238 papers reviewed, 61 were related to teleconsultation. Two applications represented the teleconsultation service delivery model: Assistive Device Teleprescription and Expert Teleaccess.

Assistive Device Teleprescription is a clinical application of teleconsultation where clinics located in rural settings expand the availability and expertise of their onsite clinician(s) by interacting with an expert clinician from a metropolitan area. Assistive device teleprescription may be applied to orthoses, wheelchairs, and augmentative communication devices (Lemaire, Necsulescu, & Greene, 2006). In the remote wheelchair prescription system, an expert clinician can join a wheelchair assessment and fitting process via a videoconference system.

A second application, *Expert Teleaccess*, is a teleconsultation service that allows a clinician who practices in a rural setting to access the expertise of a specialized clinician within a clinic or hospital. Iwatsuki, Fujita, Maeno, & Matsuya (2004) described the use of Expert Teleaccess to train physical clinicians in rural areas. The process is initiated by transmitting movement pictures of the client to the expert clinician in the metropolitan hospital. After analyzing the movement pictures, the expert clinician provides inputs on the client’s treatment plan. The rural clinician finalizes the treatment plan by combining the expert inputs with the client’s preferences.

2.2.2 Telehomecare

Three clinical applications that represented the telehomecare service delivery model were reviewed: In-home Teletraining, Home Modification Teleassessment, and the Telesupport Network.

The In-home Teletraining service delivery model enables a home-based client to learn and practice activity of daily living tasks with the guidance of a distant clinician and a home-based technician. Hoenig et al., (2006) described a protocol to deliver in-home teletraining to adults with mobility impairments. The training session employed a camera connected to a standard videophone line. This configuration allowed the distant clinician to monitor the process in real-time, remotely. Feedback from the clinician was transmitted through the audio line. The client-side used a wireless headset to receive the audio feedback; thus enabling the client to move freely during the training session.

Home Modification Teleassessment is a clinical application of telehomecare that allows an architect/accessibility expert to evaluate the accessibility of the client's home (Sanford et al., 2006). In this application, technicians visit the client and capture specific images of their home. An architect/accessibility expert remotely uploads and analyzes the images. Kim & Brienza (2006) extended the approach further by building 3D models of the clients' homes to allow virtual navigation. Based on the models, the architect/accessibility expert can provide a set of recommendations to make the home more accessible.

Telesupport Network is a clinical application of telehomecare that provides ongoing/lifetime support for the client via a network of healthcare resources. The network provides a web-based care coordination system that enables homecare staff to interact with providers from acute rehabilitation sites. Additionally, the network can provide supplemental information about homecare, rehabilitation, and other education resources. The network was constructed to address specific circumstances that can be problematic to rural clients: medication noncompliance; social isolation and inadequate supervision; limited access to specialty service; and lack of communication between homecare agency and hospital (Demiris, Shigaki, & Schopp, 2005). The network can also connect peers with similar rehabilitation needs (Schopp, Hales, Quetsch, Hauan, & Brown, 2004).

2.2.3 Telemonitoring

Telemonitoring is perhaps one of the most frequent applications of TR, with significant growth due to the availability of inexpensive and nonintrusive environmental sensors that can be placed in the home, and the advancement of wireless networks. An example includes independent-living telemonitoring which uses a range of devices, from the simple emergency call button to sophisticated home sensors. The goal of this telemonitoring application is to allow clients to live independently while their health and safety are monitored remotely by health providers (Pare, Jaana, & Sicotte, 2007).

Another example of telemonitoring is *job telecoaching*. An automated agent capable of providing instant feedback is coupled with the client as a partner. The device is programmed to identify missing steps or false movements made by the client. By creating a model of the client's movement and comparing the model with the correct movement model stored inside the device, instant feedback is produced to remind the client of the missing or false movement (McCue, Hodgins, LoPresti, & Bargteil, 2008).

2.2.4 Teletherapy

Three clinical applications were reviewed to represent teletherapy: teleneuro/orthopedic-rehabilitation, teleaudiology/teleSLP, and postsurgical teletraining.

Teleneuro/orthopedic-rehabilitation is the clinical application where neural/orthopedic-related rehabilitation therapy is delivered remotely. This clinical application category includes post-stroke, traumatic brain injury, and orthopedic TR. Feng and Winters, (2007) combined an off-the-shelf force feedback joystick with instant messaging and videoconferencing to create computer-based assessment tools for neurorehabilitation. These tools also provide instant evaluations of therapy performances that are integral to the therapeutic process. The computer-based tools and the goals they established (e.g., game achievements and targets) help motivate the client to sustain their interest and therapeutic engagement. Moreover, computer based tools provide digital metrics with a higher sensitivity to the client's subtle changes (including range of motion and pressure strength) compared to traditional clinical assessment scales. Virtual reality is also be used to provide TR. Virtual gloves (Placidi, 2007) and haptic devices provide force-feedback, allowing the client to interact with an immersive virtual reality environment in the therapy session.

Teleaudiology/TeleSpeech-Language-Pathology (TeleSLP) is a clinical application that provides speech-language therapy and audiology services at a distance. TeleSLP utilize both synchronous and asynchronous communication modes. Real-time interaction is employed to identify facial gestures and expressions, while a “store-and-forward” method is used to send numerical data to the clinician. In addition, video is stored and forwarded to provide higher-quality video recording without the need for high bandwidth (Hill et al., 2006). By using a store-and forward method, data metrics are aggregated and analyzed to deliver personalized therapy for the client.

Postsurgical teletraining is the clinical application to deliver remote rehabilitation after a surgical process. Rehabilitation for post-surgery interventions concentrates on regaining range-of-motion, strength, and relieving sensitivity in the surgical area (Heuser et al., 2007). Teleneuro/orthopedic-rehabilitation and virtual reality are used to provide remote training for the client. However, postsurgical teletraining generally focuses more on the continuity of self-training and requires less real-time interactivity with the clinician. Data is uploaded periodically and aggregated in the server for the clinician’s review.

2.3 TECHNOLOGIES OF TELEREHABILITATION

Based on the exploration of the current state of research in TR, the technology used can be categorized into two: synchronous and asynchronous. Synchronous technologies are technologies that allow real-time interaction and communication between its users. For example, videoconferencing is a synchronous technology that allows clinician to interact with their clients or with other collaborating clinicians. Synchronous technologies are used mostly in teletherapy and teleconsultation. Asynchronous technologies are technologies that store information to be used in a later time. For example, a store-and-forward system to send numerical or textual data to clinician is an asynchronous technology that allows clinicians to analyze their clients in their own time. Asynchronous technologies are used mostly in telehomecare and telemonitoring.

The following is a list of examples from the recent work on TR and the type of technologies being used (Table 2)

Table 2 Recent Work in Telerehabilitation and Modes of Telecommunication

TR Category	TR Service	Technology	Project Site
Teleconsultation	Virtual Goniometer – standard motor assessment in remote setting	Synch: Broadband network for both audio-video	University of Minnesota, Minneapolis, MN (Durfee, Savard, & Weinstein, 2007)
Telehomecare	In-home rehabilitation for adults prescribed with mobility aid	Synch: Audio and video through telephone line	VA, Durham, NC (Hoenig et al., 2006)
Telehomecare	Spaced Retrieval training for adults with chronic traumatic brain injury	Synch: Phone call Asynch: Storage of information after phone call	Florida State University, Tallahassee, FL (Bourgeois, Lenius, Turkstra, Camp, 2007)
Telemonitoring	Augmenting post-heart failure telemonitoring support	Synch: phone call Asynch: fax	VA, Ann Arbor, MI (Piette, et al., 2008)
Telemonitoring	Remote Console (ReCon) general telerehabilitation system	Synch: Audio-video, chat Asynch: post-test graphs, and patient exercise monitoring.	Physical Therapy, UMDNJ (Lewis, Boian, Burdea, & Deutsch, 2005)
Teletherapy	Haptic telerehabilitation after stroke or brain injury	Asynch: centralized server and database (information transferred through Internet)	The Jerusalem Telerehab System (Sugarman, Dayan, Weisel-Eichler, & Tiran, 2006)
Teletherapy	Assessment of motor speech disorder	Synch: Real-time videoconferencing over the Internet Asynch: store-and-forward info of client assessment	Univ. of Queensland, Australia (Hill et al., 2006)
Teletherapy	Post-stroke motor rehab therapy based on augmented feedback	Synch: Virtual reality and video conferencing	Univ. of Padova, Italy (Piron et al., 2008)
Teletherapy	REmote SPEech-language and Cognitive Treatment (RESPECT)	Synch: Internet-based videoconferencing with data sharing feature	National Rehabilitation Hospital, Washington, DC. (Brennan, Georgeadis, Baron, & Barker, 2004)

2.4 ADOPTION OF RESEARCH IN TELEREHABILITATION INTO CLINICAL USE

Brennan et al. (2008) suggested that usability of the technology to provide TR is the key to TR's adoption in day-to-day clinical activities. Two components of usability were listed: ease of use and efficiency. Based on the previous exploration, most researches in TR currently focus on digitizing and transmitting information related to rehabilitation from traditional face-to-face encounter to clinicians over the distance. The common approach to implement TR is to purchase and utilize non-integrated systems that may facilitate this purpose. A simple TR (such as telemonitoring or telehomecare) may utilize only one or two systems, while a complex TR (such as teleconsultation or teletherapy) may utilize more than three systems to assist the session. In previous chapter (1.3.1), the use of multiple systems has been discussed as being contrary to the Brennan's suggestions as it introduces both difficulty in use (due to the increased burden to the clinician from operating multiple systems at the same time) and decrease of efficiency (due to the fractured information flow).

In section 1.3.2, integrated system has been proposed as a solution to mitigate multiple systems problem. The integrated system functions as the manager of information flow between systems that support the TR. This approach allows the information to be streamlined and stored in a centralized, secure location, which ensures the integrity of the information. Accessing the information from a centralized location streamlines the work process of clinicians, which could potentially increase the efficiency of the service. The combination of ease of use and increased efficiency would result in the overall increase of the system's usability.

To further make the integrated system attractive to clinical use, several limitation and challenges of TR has to be resolved, including:

- *Limited funding and reimbursement to sustain the service.* Until today, only several types of TR are reimbursed through Medicare, such as tele-neuropsychology. Only a handful of insurance companies have policies for TR, while others follow the rules issued by Medicare. Healthcare providers also request for more cost-effective studies to justify the adoption of TR into daily practice (Seelman, Hartman, 2009). Therefore, the integrated system used to support TR would be required to induce as minimal financial impact as possible to the client and service provider.

- *Questions in security and ethical issues*. TR is also faced with the issues of creating a service that is available anywhere, anytime, yet with proper security to protect the privacy and confidentiality of individuals. Without enough protection, individuals information may be compromised, which may lead into legal and ethical issues concerning TR. Therefore, the integrated system used to support TR would be required to have the best security measure possible while still allowing ease of use and access to information necessary for the service.
- *Open for the future advancements.* As an emerging field, most of current TR researches focus on creating instruments to deliver rehabilitation services remotely or comparing between TR and face-to-face service. In addition, many rehabilitation practitioners still have limited awareness of the existence of TR techniques and technologies that may be appropriate for their clients. As more technologies and techniques emerge from these researches, the integrated system will be required to accommodate these advancements into clinical use in timely manner.
- *Scalable network to access the service anywhere.* The integrated system need a telecommunication network that allows swift addition of new sites, is able to handle different type of information flow, and is able to provide access to TR from anywhere. These requirements make the Internet an ideal network for the integrated system for TR. Until recently, the Internet was not considered an option due to several limiting factors, including small bandwidth size, limited access from rural areas, and lack of an integration support. However, by the end of 2006, the access of broadband connections among Internet users in the United States was estimated to reach 80% (Madden, 2006). The availability of these high-bandwidth connections provide a channel for various types of data to be transmitted between locations. The advent of Web 2.0 further increases the appeal of the Internet as a platform for wide range of services, ranging from simple services such as online document storage to demanding, interactive services such as videoconferencing. Development of an integrated system on top of the Internet will allow the integrated system to inherit the characteristics and benefits of the network naturally.

Fitting the integrated system into all the requirements and limitations of TR required a model to guide both the design and the development process. The next chapter would describe in detail the model that was established for this purpose.

3.0 INTEGRATED TELEREHABILITATION SYSTEM

3.1 MODEL OF THE INTEGRATED SYSTEM FOR TELEREHABILITATION

The integrated system has been presented as a potential solution to deliver services in TR. Designing the integrated system for a specific TR, however, may be challenging due to both TR's requirements and the diverse range of services. At the Rehabilitation Engineering Research Center on Telerehabilitation (RERCTR), a model had been formulated to identify the key characteristics of the integrated system. This model led to the formation of a set of guiding principles to design, develop, and customize the integrated system. Both the model and the guiding principles are applicable across TR services. This methodology to design, develop, and customize the integrated system into TR is called the PITT Model.

3.1.1 Key Characteristics of the Integrated System

Based on the requirements and limitations of TR, five important characteristics of the integrated system were identified: openness, extensibility, scalability, cost-effectiveness, and security (Figure 6).

- *Openness.* At the core, the system needs to be open to any IT components required by TR. This characteristic denotes the need of an ability to interface with any IT components and manage data exchange between any IT components required by TR as necessary. These IT components may range from simple collaboration modules to advanced components, such as decision support system or videoconferencing systems.
- *Extensible.* Many applications of TR have specific requirements, such as the need of having a private communication channel between the clinicians, the need to

share document in real-time collaboration, or the need to send stimuli to remote site. These requirements may be introduced by the TR provider's business model, existing clinical situation, or organizational policies. Extensibility characteristic conveys the need for easy customization of the system's components to adhere to the specific requirements of each application of TR. For example, the system can be customized to show only the features that clinicians need to complete their tasks instead of showing all the features that are available in the system.

- *Scalable.* Scalability characteristic signifies the system's ability to expand rapidly to meet the demands of TR. This characteristic is important to support the fast growth of TR as future collaboration with additional sites can be included into the network in a timely manner. The addition of new sites may bring new experts into the service, or new populations to be served through TR.
- *Cost-effective.* The rising cost of healthcare demands that the system to support TR be as cost-effective as possible, incurring minimal cost to the TR providers and clients, while maximizing the benefits gained. Generally, cost-effectiveness requires the platform to justify the use of each IT component by measuring the amount of benefits gained from using the component compared to the amount of resources spent to deliver and maintain the component. For example, low-cost open-source modules can be utilized to build the IT component for the integrated system.
- *Secure.* The increasing demands to protect confidentiality and privacy in healthcare system and the potential liability issues drive the need of a secure system. The security characteristic is an important role in building the trust that clinicians need to adopt the system into their daily practice. Employing proper security measures, such as utilizing role-based access system, is an example in creating a secure, trusted, and confidential environment.

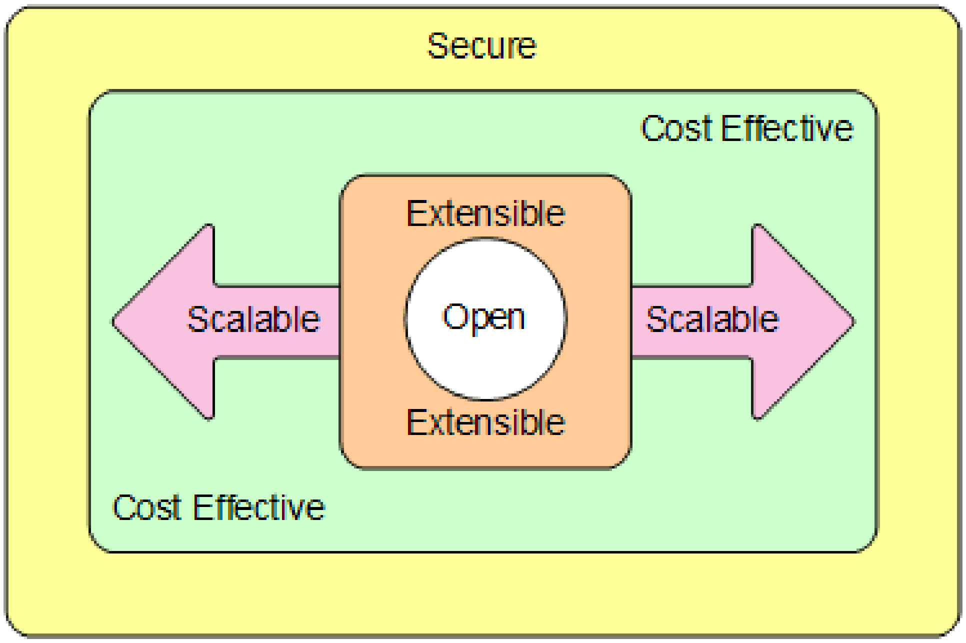

Figure 5 Key Characteristics of the Integrated System from the PITT Model

3.1.2 Guiding Principles to Design, Develop, and Customize the Integrated System for Telerehabilitation

The need of a system with high usability and the required key characteristics led to the formation of guiding principles for the development of the integrated system. These guiding principles are applicable across various applications of TR:

- User-centered: users should be actively involved in the design and development process to ensure the compliance of the system with the real needs of TR.
- Usability focus: the system should be evaluated and refined to remove problems that hinder users from using the system efficiently and effectively to accomplish any tasks in TR. The system should also be intuitive and easy to use to minimize the need of individual training.
- Choice of open technology: the system and its components should be based on the Internet protocol, including its derived technologies to absorb the natural advantage of the Internet network, including access from anywhere-anytime, extensible, scalable, and open.

- Controlling the cost: the system should maximize the use of open-source technology or other low-cost, off-the-shelf technology.
- Secure and confidential: the system should comply with current security policies. The system should also be able to adopt newer security improvement when available.

3.2 SYSTEM DEVELOPMENT LIFE CYCLE FOR TELEREHABILITATION

System development life cycle (SDLC) is a framework to control and manage the development of an IT system. To develop the integrated system, the guiding principles were adapted into a standardized SDLC. The use of SDLC ensured the development of the integrated system met the specific needs of TR, supports TR effectively and efficiently, and is cost-effective to maintain and develop.

The SDLC for TR follows a modified prototyping model, called the spiral life-cycle model (Clarke et al., 1991; Engelbrecht, Rector, & Moser, 1995). The spiral life-cycle model consists of four phases: verification, design and development, validation, and evaluation. O'Leary (1993) describes the distinction between these phases: verification focuses on the technical appropriateness of the system, design and development focus on the development of the system prototype, validation ensures the appropriateness of the system to the tasks, and evaluation assesses the functions, usability, and value of the system.

3.2.1 Verification Phase

The technical appropriateness of the integrated system depended on two components: the needs of the TR application and the technology used to provide the solution for. Therefore, in the verification phase, two types of requirement assessments were necessary:

- *Identification of the TR requirements.* The requirement identification process focused on understanding the rehabilitation service itself. The result of this step was a list of personnel, tasks, and information required to perform the rehabilitation service in remotely. The method to identify these requirements included daily observation of the face-to-face rehabilitation environment, interview with stakeholders, and analysis of the documents used daily by clinicians.

- *Identification of the technology to meet the TR requirements.* Identifying the appropriate technology to meet the requirements of TR was important in designing an optimal integrated system for TR. For example, a typical IT system for teleconsultation is videoconferencing over high-bandwidth network, while telehomecare typically requires only low to moderate bandwidth. The areas of telemonitoring and teletherapy generally require a moderate to high bandwidth. The process to identify these technologies ranged from identification of currently available telecommunication network between TR sites, creation of cost-benefit comparison between IT components to exploration of emerging technologies to provide similar rehabilitation experiences to face-to-face encounters. This process produced a list of potential IT components that can be used to meet the requirements of the application of TR.

The result of the verification phase was a matrix describing the relationship between requirements and the IT components to meet the requirements. This matrix shows how each IT component will be used to support corresponding requirements and what type of data is required.

3.2.2 Design and Development Phase

The design and development phase focused on the process of creating and altering IT components to develop the integrated system according to the TR requirements. The design process focused on the creation of four key designs:

- *The design of the system.* As described by the PITT model, the core of the system was designed to be open (can interface with any IT components required by TR and manage information between IT components). The final system was also designed to be scalable (enable new sites to join the network with minimal effort).
- *The design of interfaces between IT components and the system.* The interfaces were generally used to share information between IT components and the core of the system. Thus, the design of the interface focused on creating methods to store information from the IT components into the core system and retrieve information

from the core system. For example, a videoconferencing component may require authentication data to secure the communication properly. Based on this requirement, an interface to retrieve the authentication data type from the core system was developed. Using this interface, the videoconferencing component could communicate with the core system to retrieve the required authentication data. Afterward, a method to store the authentication data type into the core system was developed. This method was used by a 'log-in' component to store authentication data into the core system. With this approach, the 'log-in' component could communicate with the videoconferencing component through the core of the system. Similar methods were also developed to allow access, store, and retrieval of data from the core of the system effectively, removing any potential data redundancy.

- *The design of the system's security protocols.* The security protocols of the integrated system were designed to be 'transparent' to the user. With this design, the security of the system provided maximum security benefits while minimizing user's effort to conform to the protocol. For example, a highly secured system that requires clinicians to be approved to perform any actions, thus denying the clinicians from retrieving patients' information on demand would have a negative impact on the system's adoptability by clinicians in their daily activities. To avoid this situation, the integrated system was designed with role-based access and logging, which provided tracking of user's activities and allowed roll-back from any errors.
- *The customization plan.* As previously discussed, most applications of TR require specific modifications to be implemented into the system. The specific modifications generally depended on organizational factors, such as specific security policies, or specific document templates that were used only in certain clinics. A customization plan was designed to accommodate these specific requirements into the integrated system to support TR.

The development process focused on implementing the design into a working system to support a TR application. In general, three steps were necessary in the development process:

- *Development of system prototype.* The initial system prototype was developed as a proof of concept to the design. This prototype was then introduced to the users. The introduction of the prototype to the users allowed developers to gain feedbacks to further refine the prototype to accommodate users' activities.

- *Customization of prototype.* Based on the feedback from the initial system prototype and the customization plan, the prototype was developed into a release candidate version. The release candidate version was a near-finish prototype of the system, with many of the features implemented.
- *Optimization of prototype.* The final step in development process was the optimization of the release candidate version. In this step, the development focused to identify and mitigate any new requirements introduced by TR sites. The code of the system was also optimized to improve the performance by removing unnecessary codes used for testing/debugging purpose.

3.2.3 Validation Phase

The aim of the validation phase was to ensure the appropriateness of the integrated system developed to support TR to the requirements of TR. Two approaches were used in the validation phase:

- *Conducting test-run in pilot sites.* Conducting test-run in pilot sites was necessary to identify potential hurdles to set up the system in a small scale, real world setting. To conduct the test-run, several rural clinics were invited to deploy and use the integrated system in their daily routines. The result of the test-run was a guideline to deploy the system properly.
- *Conducting formative usability assessment that focuses on identifying potential refinement for the system.* The usability assessment focused on understanding how the system was used personally by each clinician during any TR activities. During a formative usability assessment, the usability barriers that hinder a clinician from successfully completing their tasks using the integrated system were identified. New requirements were also identified to further improve the usability of the system. The results of the formative usability assessment were usability recommendations, which were used to refine the system in the next cycle of the system development process.

3.2.4 Evaluation Phase

During the evaluation phase, the system's usability and value to support TR was analyzed through a summative usability assessment. This study compared the integrated system's usability with non-integrated systems which were commonly used to support TR. In general, four key usability areas were being used as the variable to compare the usability of the system: can the user perform and eventually finish their task using the system (effectiveness), can the user complete their tasks in a timely manner (efficiency), can the user progress with their tasks after encountering problems/errors (error recovery), and does the system satisfy the user’s expectation (satisfactory).

3.3 POTENTIAL BENEFITS OF THE PITT MODEL

The advancement of the Internet technologies opens the possibility for the development of an integrated, cost-effective telerehabilitation system. The current speed of the Internet makes videoconferencing, an important component of a TR system, over the Internet practical. The broadband penetration, that reaches rehabilitation clinics and homes, provides opportunity for widespread deployment of a TR system. The availability of open source components and commodity equipment such as web camera allows the development of a low cost TR system from the ground up. Engbers et al. (2003) had shown that commodity equipment and open source components are sufficient to support TR. The PITT model allows the integrated system to inherit all these advantages naturally due to its openness.

TR provides clear benefits in underserved areas, such as rural communities, where expert clinicians are in short supply. The integrated system guided by the PITT model will allow the expansion of the service in rural or remote area clinics to include services from metropolitan clinics in their assessment. This approach has the potential to reduce service delivery costs associated with travel and time, for both clinicians and clients. For example, adding a 'tele' aspect to wheelchair prescription service in a rural area has improved access to experts originally available only in urban areas, which reduced the need for individuals to travel to urban rehabilitation centers to seek assessment.

The PITT model’s focus in usability and putting user as the center of the design allows the development of an efficient and easy to use integrated system. Goldschmidt (2008) noted that not only health information system with high usability is easier to adopt, this system may also result in the reduction of the total cost of service due to the increased efficiency gained from using the system.

The integrated system developed by following PITT model’s principles also has the potential to improve the quality of care provided by the TR provider. Two aspects of quality improvement have been perceived: data integrity and skill building through education. During the preliminary works, the study has identified that centralizing data allows clinicians to have timely access to client's information anytime from anywhere. With the rising trend of digitizing client's health data into an electronic format which is stored inside an electronic health record system, data integrity becomes a key aspect in maintaining the continuity of care between different healthcare providers. Integrating secure multimedia database and the Internet allows multiple healthcare providers (i.e. clinicians, physicians, and assistive technology device suppliers) to query into a single data source. This approach reduces the possibility of data mismanagement, including missing data and obsolete data. Storing the data in a secure system will also improve the rehabilitation service's adherence to the industry’s security requirements, such as the Health Insurance Portability and Accountability Act (HIPAA). Data integrity aspect allows clinicians to make a complete, informed decision over their client's treatment.

The integrated system may also provide skill building through education to the clinicians located in rural areas. Jennet and Premkumar (1996) shows a trend that TR gives an improvement in the communication between the interdisciplinary team involved, which produces educational benefits for all team members in the project and reduces professional isolation. By providing access to a centralized database which contains client’s health data tracking and multimedia materials (such as archive of teleconsultation sessions or assessment video for training purpose), the integrated system has the capability of delivering educational materials over the internet. These resources can potentially provide clinicians with access to online education to perform or improve their skills to provide the rehabilitation service themselves.

4.0 AN INTEGRATED TELEREHABILITATION SYSTEM FOR REMOTE WHEELCHAIR PRESCRIPTION: VERIFICATION OF NEEDS

4.1 REHABILITATION TELECONSULTATION: REMOTE WHEELCHAIR PRESCRIPTION

The model and method to develop and transform rehabilitation service into TR described in this dissertation has been employed in several project within the RERCTR, including a remote wheelchair prescription (RWP) project (Schein, 2009), a telemonitoring project for speech-language pathology (Parmanto, Saptono, Murthi, Safos, & Lathan, 2008), and a project to support job-coaching (McCue, Hodgins, LoPresti, & Bargteil, 2008). Although the method is generalizable to most applications of TR, RWP has been chosen as an example on how the work described impacts and transforms a traditional face-to-face rehabilitation service into TR.

RWP is a TR effort to deliver wheelchair prescription consultation service remotely to clinics in rural Pennsylvania. A traditional wheelchair prescription service generally requires clinicians with expertise in assessing and choosing the correct wheeled mobility and seating intervention that matches with the client's functional needs in home, work, and community environments. However, access to clinicians with these specific training and knowledge skill sets is usually limited to metropolitan areas, narrowing the locations where individuals with mobility impairments can receive appropriate care. Due to this limitation, individuals with mobility impairments residing in rural and/or remote areas are considered underserved (Cooper, Trefler, & Hobson, 1996; Batavia, Batavia, & Friedman, 2001). The small numbers of experts in this specific field are expected to serve 2.2 million people who use wheelchairs for their daily mobility (Kaye, Kang, & LaPlante, 2000). This number will continue to grow as the baby boomer generation is coming of age and individuals are surviving traumatic events due to medical advancements. The pressure of reimbursement and the number of abandoned assistive technologies also drive the need of having clinicians to conform to best practices and available gold standards.

TR has been viewed as a potential option to deliver clinical service in these areas (Kinsella, 1998). In remote wheelchair prescription project, TR is used to provide consultation access to expert clinicians in metropolitan area center. Through videoconferencing, expert clinicians provide teleconsultation to guide clinicians in rural area. Today, the remote wheelchair prescription service has been delivered to five clinics in rural Pennsylvania. Due to the extensive telementoring provided through TR, all of the clinics are operating independently using the standards of practice employed by TR, requiring no to minimal teleconsultation. The project is now exploring the possibility to deliver the service to other countries, including Mexico and Brazil.

4.2 REMOTE DELIVERY OF WHEELCHAIR PRESCRIPTION SERVICE

The use of a properly prescribed fitted wheelchair enables users to successfully live, both at home and within the community, by improving independence and enhancing physical functions. The assessment of the user's needs and the process of matching those needs with an appropriate wheelchair are essential to ensure a successful outcome. Both clinical interventions, however, are complex and challenging. To properly prescribe a wheelchair, clinicians need to be exposed to or have a specialty certification in this particular area, which requires the ability to analyze beyond only the user their functional needs, but in addition to their functional environment and funding mechanisms. This certification generally comes from professional organization, such as the Rehabilitation Engineering and Assistive Technology Society of North America, and is granted to a service provider that has the capability to analyze the needs of consumers with disabilities, assist in prescription of appropriate assistive technology, and provide training in the use of the prescribed technology.

The wheelchair prescription process is typically completed by a multidisciplinary team, consisting of client, physician, clinician, caregivers, and rehabilitation technology supplier (RTS). Each individual involved have unique attributes that are necessary to properly assess the client; physician usually initiates the process by determining the need of a mobility device followed by a referral to a wheeled mobility and seating clinic; clinician assess the client's mobility and functional limitations, while the rehabilitation technology suppliers provides the clinician with extensive knowledge of devices and the client’s living environment condition.

Due to the extensive skill sets required, the delivery of wheelchair prescription service in rural and remote areas faces major issues, including the availability of health care providers with proper professional and/or technical skill to prescribe wheelchairs and the high cost of service delivery. Currently, only a handful of clinicians with expertise in seating and mobility are available in most states whereby they are mostly concentrated in metropolitan areas. The concentration of experts often creates shortages of professionals and technical resources crucial to the delivery of services related to specialized medical fields in rural areas (Callas, Ricci, & Caputo, 2000). The small numbers of experts are expected to serve 2.2 million people who use wheelchairs for their daily mobility (Kaye, Kang, & LaPlante, 2000). In addition to the availability problem, the large distance separating expert clinicians and the wheelchair users in rural areas means excessive travel times, either by professionals or by the individuals themselves. Ultimately, individuals in rural or underserved areas often receive a decreased quality of rehabilitation service.

Recently, there is a growing trend on the use of technology for remote assessment and intervention in medicine (Bashshur, 2002) and rehabilitation (Lemaire, Boudrias, & Greene, 2001; Torsney, 2003). One aspect of this endeavor is to have an expert in a specialty area such as seating and wheeled mobility to represent the clinical knowledge from a metropolitan center to assist in the decision-making along with the rural generalist clinician. Implementing telerehabilitation (TR) to support the assessment phase of the project has the potential of reducing the distance and the time used by the skilled professionals to travel, which then can be used to provide more services to an underserved population.

Only a handful of studies have analyzed the use of TR in the field of seating and mobility. Malagodi et al. (1998) compared the use of videoconferencing equipment through plain-old-telephone-system (POTS) lines and Integrated Services Digital Network (ISDN) lines to complete seating and mobility assessments. The study evaluated eight clients being assessed through videoconferencing, four using the POTS line and four using an ISDN line. The results of the evaluations from the videoconferencing assessment were compared with the results of evaluations from the face-to-face assessments. The comparison showed that the client’s primary condition and major problems were correctly identified using both approaches, however the assessments conducted through videoconferencing took longer time to complete compared to face-to-face assessments due to slower data communications and unstable video images.

Several other studies also showed that TR is a potentially useful tool for wheelchair prescription service. Cooper et al., (2002) for example, compared the type of wheelchair used by individuals to the recommendation of clinician via TR and in-person assessments. This study demonstrated a high level of agreement in recommendation between TR and in-person assessments. Other studies have also shown that TR has the potential to provide evaluation, treatment intervention, follow-up, and community re-entry (Phillips, Temkin, Vesmarovich, & Burns, 1998; Phillips, Temkin, Vesmarovich, Burns, & Idleman, 1999).

4.3 IDENTIFICATION OF NEEDS

RWP adapted the service delivery model of the wheelchair prescription service offered by the Center for Assistive Technology within the University of Pittsburgh Medical Center (CAT-UPMC). Observation of CAT-UPMC's workflow in delivering the service resulted in the identification of four main phases: initial data collection, data documentation/reporting, finalizing the documentation through multidisciplinary team collaboration, and system delivery/fitting. **Initial data collection phase** included activities of gathering client's demographic information, initial assessment data, living environment assessment data, and other administrative data. **Data documentation/reporting** phase focused on activities to initialize clinical documentation for medical necessity, which was essential to create the baseline value for analyzing the outcome of the prescription service. **Finalizing the documentation** phase focused on gathering the complete information about the client, including the living environment condition of the client. This phase involved all members of the multidisciplinary team working closely with the client thus required heavy collaboration efforts between physicians, clinicians, and RTS. Finally, during the **system delivery/fitting** phase, the clinician assessed the mobility device during client trials to ensure that all recommendations and client's needs were met. The clinician also collaborated closely with RTS to see if there are any maintenance and/or alterations to be made to the mobility device.

Translating the four workflow phases of the traditional service delivery model into TR service delivery model required a transformation of activities from face-to-face setting into remote setting. Several key questions need to be answered prior the transformation of the activities, including:

- How would the multidisciplinary team change in TR setting?
- How would the multidisciplinary team perform the activities of the four workflow phases in TR setting?
- What kind of information that each team member need in TR setting?

4.3.1 Multidisciplinary Team in TR Setting

The integrated system for supporting RWP can be viewed as a type of computer supported cooperative work (CSCW) system that support remote collaborative effort from multiple sites. Literatures in CSCW suggested the use of a development strategy that focuses on the operational units of the service and the use of appropriate technologies to support the remote collaborative effort of the operational units as a group. This approach has the potential of improving the adoption of the system in healthcare settings (Pinelle & Gutwin, 2006).

The most common source of information to identify the operational units of a service is the job and task descriptions. Job and task descriptions generally outline the main activities and accountabilities of individuals involved in the service (Cashmore & Lyall, 1991). Analyzing the job and task descriptions from the traditional wheelchair prescription service allowed the identification of the type of tasks in the service, the operational units (‘roles’) that are required to complete the tasks, and the individuals inside each of the operational units that performed the task. For example, two roles were identified by analyzing the description of client assessment task in the traditional wheelchair prescription service: physician and clinician. Transforming the client assessment task from face-to-face into TR would split the role of clinician into two: expert clinician and generalist clinician. The split was necessary due to the limitation of TR, in which the expert clinician has no direct physical contact with the client. In TR, generalist clinician acted as the extension of the expert clinician for any task that required physical contact.

Using this approach, four roles were identified to successfully complete all workflow phases of wheelchair prescription service in RWP:

- **Physician.** Physician role dealt primarily with the first phase and the third phase of the workflow. This role was responsible to assist with the initial assessment and approve the device recommendation. Most of physician role's tasks can be completed without the support of the integrated system. Physician is generally located at rural/remote location.
- **Generalist clinician.** Generalist clinician role is required in all of the phases. This role's primary responsibility was as the front-face of the service to interact with the client and as the extension of the expert clinician in any physical assessment. Generalist clinician role is located at the remote/rural clinics.
- **Expert clinician.** Expert clinician role was primarily the quality assurer of the service. An expert clinician is an occupational therapist or physical therapist with an assistive technology professional certification and five or more years of experience in the area of wheeled mobility and seating. Traditionally, expert clinician is located at metropolitan area clinics. However, with TR, expert clinician can be located anywhere as long as the location is connected to the Internet. Expert clinician is also required in all of the phases.
- **Rehabilitation Technology Supplier**. RTS role was involved mainly in the second and fourth phase. They were responsible in assessing the client's home environment and updating the client's information according to the home assessment result. RTS is located at rural/remote location.

4.3.2 Performing Collaborative Activities in TR Setting

Two types of collaboration need to be supported in RWP: real-time (synchronous) collaboration and non-real-time (asynchronous) collaboration. Synchronous collaboration support was required to provide real-time teleconsultation channel between team members that were located in different sites, for example, communication between expert clinician and generalist clinician. Asynchronous collaboration support was required mostly in documentation process, in which each team member may improve the document by adding new information about the client whenever available. For example, RTS may add new information about client's home accessibility after performing evaluation of the client's home environment. This information may be added after or before client assessment process by the clinicians. In CSCW, the real-time teleconsultation is categorized as a ‘remote-synchronous collaboration’ (a collaborative work done in two different places at the same time), while the documentation process is categorized as a ‘remote-asynchronous collaboration’ (a collaborative work done in different places at different times).

The following are requirements for the remote-synchronous collaboration support obtained through interviews with clinicians from the area of seating and wheeled mobility:

- Should support generalist clinicians at rural clinics by providing knowledge and guidance (Burns et al., 1998)
- Should allow expert clinicians to join the assessment to ensure that the assessment session meet the standard of practice used in the traditional face-to-face setting
- Should have a visual streaming with high clarity to ensure the best quality of direct evaluations by the expert clinicians during the assessment (Malagodi et al., 1998)
- Should allow the sharing of assessment related materials concurrently during the teleconsultation
- Should provide a communicate channel that is secure for privacy and confidentiality; and
- Should be able to record and archive the sessions to review at a later point

The following are the identified requirements of the remote-asynchronous collaboration support, including:

- Providing a support for online data management and collaboration system (Winters, 2002)
- Providing an ability to manage service workflow and associated activities
- Providing an ability to share the data and information gathered through the process to help with the decision making process
- Providing a secure database system to ensure data integrity and confidentiality

Figure 6 illustrates the conceptual interaction flow between team members inside the workflow of RWP. As previously discussed, four roles formed the multidisciplinary team in RWP, including expert clinician from CAT-UPMC at Pittsburgh, PA and a team consisting physician, generalist clinician, and RTS from rural clinic site. These roles performed the four phases of the wheelchair prescription service workflow using an integrated system that supported two collaboration types: synchronous and asynchronous.

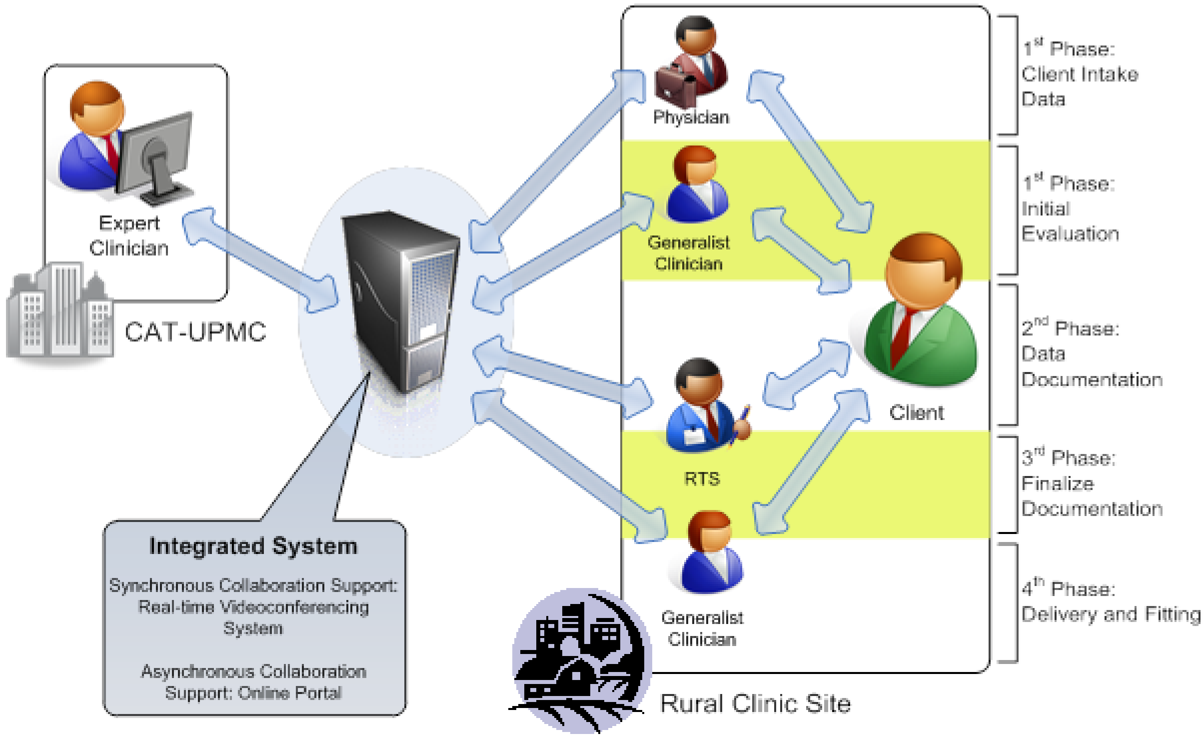

Figure 6 Conceptual Interaction Flow of the Remote Wheelchair Prescription Service Team

4.3.3 Information for Activities in TR Setting

Transforming the interaction inside the workflow depicted in figure 41 required the integrated system to serve as a platform for information exchange between the multidisciplinary team members (including physicians, clinicians, and RTS) and their clients in real-time and non-real-time situation. The accuracy of the information exchanged through this system is essential in making informed decisions regarding the client's needs (Tan, 1998). The information is considered accurate if the information provided is appropriate to meet the need of the task that is being performed by a specific role. For example, clinician can recommend a power wheelchair with tilt and recline function to a client if the clinician know that the client has problem with weight shifting. Table 3 lists all the tasks within each of the workflow phase in RWP.

Table 3 Phase and Steps of Remote Wheelchair Prescription

Service Delivery Process in Remote Wheelchair Prescription Project	
Initial Data Collection	Initial evaluation by generalist clinician with assistance of expert clinician through teleconsultation Document initial intake data Device trial by client with assistance of RTS and expert clinician through teleconsultation
Data Documentation	Document result of trial into letter of medical necessity
Finalize Documentation	Complete clients' home assessment information performed by the RTS Send letter of medical necessity to physician for review and confirmation RTS submit completed form to funding agency
System Delivery and Fitting	Fitting and delivery of assistive device by generalist clinician and RTS with the assistance of expert clinician through teleconsultation Document outcome data Document final result data by contacting client no more than 2 weeks following delivery

The next step is to identify the type of information required by each role to complete their tasks. The following three questions were guidelines to assist the identification process:

- What information is required prior to performing a particular task?
- What decisions or problems do rehabilitation professionals face and what type of information do they need to rectify these problems?
- What information do rehabilitation professionals need to determine the success of a particular task?

The result of this process is a matrix of roles, tasks, and support from the integrated system (table 4). This table connects the roles of each team member in RWP, tasks from each role, and the collaboration support from the integrated system for the task. Listed inside the collaboration support are modules that provide the information required to complete the specific tasks. Based on the nature of their tasks, some roles may need access to both the remote-synchronous and remote-asynchronous collaboration support provided by the integrated system.

Table 4 Matrix of Roles, Tasks, and Support from Integrated System

Roles	Tasks	Integrated System Remote-synchronous	Integrated System Remote-asynchronous
Physician	Initial assessment		Client physical data
	Approve recommendation		Complete client data Letter of recommendation
Generalist Clinician	Initial assessment	Expertise from expert clinician	Client physical data
	Functional assessment	Expertise from expert clinician	Client functional status data
	Wheeled mobility trial	Expertise from expert clinician	Client preferences data
	Demographic data collection		Client administrational data
	Review client information		Complete client data Letter of recommendation
	Fitting and delivery	Expertise from expert clinician	Complete client data
Expert Clinician	Initial assessment	Client status from generalist clinician	Client physical data
	Functional assessment	Client status from generalist clinician	Client functional status data
	Wheeled mobility trial	Client status from generalist clinician	Client preferences data
	Review client information		Complete client data Letter of recommendation
	Fitting and delivery	Client status from generalist clinician	Complete client data
Rehabilitation Technology Supplier	Home assessment		Client home data
	Medical Device Justification		Letter of recommendation

4.3.4 Constraints and Limitations of Service in Rural Area Clinics

The technological constraints of clinics in rural area need to be identified and incorporated into the design of an optimal system for RWP. Several constraints have been identified, including:

- **Availability of videoconferencing equipment in rural area clinic**. Not all rural clinics had resources to procure and sustain high-end videoconferencing systems. Therefore, the system should be designed to interface with off-the-shelf equipment in mind. For example, instead of using a proprietary, high-end videoconferencing system and camera, the system should be able to provide a lower cost, desktop based videoconferencing using regular, off-the-shelf web camera that can be easily procured.

- **Availability of bandwidth in rural area clinic**. Although internet access was widely available in rural areas, an assumption that all rural clinics have the latest, high-end bandwidth should not be made. Therefore, the integrated system should have the versatility to be deployed on a wide range of network connection types, ranging from DSL to T1.
- **Level of information technology (IT) support**. Most rural clinics only have limited information technology support resources to assist the daily clinical activities. Therefore, the integrated system should be designed with ease of deployment and maintenance in mind to minimize the need of IT support.

4.4 IDENTIFICATION OF TECHNOLOGIES

In summary, RWP required an integrated system that can support both remote-synchronous and remote-asynchronous collaboration activities. The remote-synchronous collaboration activities in RWP required the integrated system to have real-time video and audio conferencing component, real-time textual communication channel (such as chat room and instant messaging system), and real-time groupware collaboration components (such as tools to present slides and multimedia files). On the other hand, the remote-asynchronous collaboration activities in RWP required the integrated system to have a set of information management technologies with components for completing delayed communication and coordination, such as email or bulletin board system, and also task coordination, such as service workflow management and document version control.

These different modalities of requirements demanded a unique integrated information technology (IT) system which need to be designed from the ground up, as existent systems were limited or not sufficient to meet all requirements. For example, popular videoconferencing systems would not be able to meet the remote-asynchronous collaboration requirements of the projects, such as tracking service workflow or supporting offline discussions. As the requirements were primarily tied to real-time communication and asynchronous, centralized data management, two main technologies were deemed necessary to build the core of the integrated system: videoconferencing and content management system.

4.4.1 Identification of Videoconferencing Technology for Real-time Communication

The process to identify the appropriate videoconferencing technology to build the real-time communication component of the integrated system began with an exploration of existing videoconferencing systems. Four videoconferencing technologies were explored: Polycom videoconferencing set, Cisco WebEx, Adobe Connect, and Dimdim. These selections of technologies represented the wide variety of videoconferencing technologies that were available in the market. The first one, Polycom, represented videoconferencing technology that was usually sold in a package/set, which includes both hardware and software. Cisco WebEx and Adobe connect represented videoconferencing technology that ran on top of a regular internet browser, which can be bought and deployed via a site-based license. Dimdim represented similar videoconferencing technology that ran on top of a regular internet browser; however this technology came from open-source project, which can be procured for free.

The exploration process followed the PITT model to identify the existence of characteristics required by the integrated system. As previously discussed in chapter 3, the PITT model's characteristics were openness, extensible, scalable, cost-effective, and secure. To satisfy the requirement of openness, the videoconferencing technology need to be able to interface with mass-market technologies (web cameras, speakerphones, etc.), able to interface with an information management system, and able to interface with any other technologies used in delivering rehabilitation service. For extensibility, the technology need to be customizable to fit into TR setting while meeting the identified TR requirements, including having the ability to produce high quality video and audio stream, archive sessions, support real-time interactivities, share documents/multimedia during a session, and support remote camera control. In scalability, the technology should be versatile enough to be deployed in a wide range of hardware. This requirement was important considering that some clinics would have the capability of supporting high-end hardware while others might not have the same resources. The cost of procurement and sustaining the technology should produce minimal financial impact to the clinics to meet the cost-effectiveness characteristic. Finally, the technology should be secured in at least three layers: authentication through password, data encryption, and access to features limited by user's roles in the service. Table 5 depicts the result of the exploration of the five videoconferencing technologies by following the PITT model requirements.

Table 5 Videoconferencing Technologies Comparison Table

Characteristics			Polycom	Cisco WebEx	Adobe Connect	DimDim
Openness						
	Able to interface with mass-market technology (camera, etc.)		Some version yes, but in majority no	Yes	Yes	Yes
	Able to interface with information management system		No	No	Yes, through the use of integrated browser	No
	Able to interface with technology used in rehabilitation		No	No	No	No
Extensible						
	Able to meet with TR requirements, including:					
		High quality video/audio stream	Yes, based on product can range from medium to very high quality	No, can produce medium quality	No, can produce medium quality	No, can produce medium quality
		Session archiving	Yes, with additional equipment	No	Yes, with additional modules	Yes, but limited to audio and video
		Real-time interactivity modules	No	Limited	Limited	Limited
		Sharing documents and materials	Yes, by connecting a separate computer	Yes	Yes	Yes
		Remote camera control	Yes	No	No	No
	Easy customization to fit into TR setting		No	No	No	No
Scalable						
	Versatile hardware requirement		No	Yes, due to use of browser	Yes, due to use of browser	Yes, due to use of browser
	Easy to expand to cover more TR sites		No	No	No	Yes

Cost-effective					
	Cost of procurement	$20k-$100k	License based	License based	$0
	Cost of sustaining system	Depend on usage	$59 per month	$375 per month	$0
Secure					
	Password-protected	No	Yes, in some product	Yes	Yes
	Protected by encryption	Yes, in some product	Weak	Weak	No
	Protected by roles	No	Limited	Limited	Limited

Source: webconferencing.org

In most telemedicine applications, Polycom and Tandberg were the two most widely used systems. These systems could easily solve the real-time communications requirements of telemedicine applications, although this solution came with a premium price. Beyond real-time communications, however, these systems fell short as the close nature of the system limit the capability of the system to be expanded to meet any other requirements. For example, the system cannot interface with equipment used regularly in a rehabilitation session, such as pressure mapping mat or accelerometer. The same limitation also applied to the rest of the technology: these technologies were geared only for videoconferencing application, with limited capability to interface with other tools that were required in rehabilitation. Based on these observations, none of these systems could be used to develop the integrated system envisioned in the PITT model. Therefore, the only solution to build the integrated system was to develop the system ground-up, combining open-source standards, off-the-shelf technologies, and homebrew modules.

The basic foundation and components to build the integrated system was adopted from open-source videoconferencing projects as these components were available in modular format and ready to be used. However, the components to deliver the video and audio stream could not be adopted from regular open-source videoconferencing projects as most of these projects were browser-based and could only produce low to medium quality video and audio. The decision was to adopt videoconferencing components from ConferenceXP, an Internet2 based open-source videoconferencing project. This project was based on AccessGrid which has been used in both research organizations and universities (Anderson, Beavers, VanDeGrift, & Videon, 2003; Anderson et al., 2003). These components were customized to fit into regular Internet network, making them more versatile and adaptable to any bandwidth condition. To produce high quality video, off-the-shelf web cameras with high quality lenses were used. Connecting these web cameras to the versatile videoconferencing components allowed high-quality video and audio stream of the rehabilitation session to be transmitted over regular Internet connection in a cost-effective fashion.

The rest of the requirements, including real-time interactivity and security, could only be met by developing the components 'in house'. Real-time interactivity modules required an extensive understanding of the nature of the rehabilitation service to be delivered. However, once developed, these modules can be used across rehabilitation services. For example, modules that allowed clinicians to send/share stimuli images to their patients could also be used to send/share images between clinicians during collaboration process. Security modules were also developed in house due to the limited security options available in most open-source videoconferencing. These modules were developed based on algorithms that had been published and used regularly to protect electronic health information.

4.4.2 Identification of Content Management System to Support Asynchronous, Centralized Data Management

Similar to the identification of videoconferencing component for real-time communication, the process to identify the content management system (CMS) component to support asynchronous, centralized information management focused on finding PITT model's characteristics within existing CMS. Five CMS were explored as candidates for the integrated system's CMS: PHP-Nuke, DotNetNuke, Microsoft Sharepoint, Oracle Portal, and IBM Websphere EIP. PHP-Nuke and DotNetNuke were open-source CMS while Sharepoint, Oracle Portal, and IBM Websphere EIP were CMS sold by third-party developers.

All CMS candidates were known to be open, both to the hardware and software used in rehabilitation service and healthcare in general. The differences came mainly from their capabilities to meet the extensibility characteristic of the PITT model. To meet the extensibility characteristic, the CMS need to be able to provide support for online data management, asynchronous collaboration tools, and tools to manage service workflow. The scalability characteristic required the CMS to allow easy addition of new modules and new users to access the information. The cost-effectiveness characteristic mainly focused on the cost of procurement of the system as all CMS would need similar cost to sustain the system for daily usage. Finally, the security characteristic required the system to protect the information through the use of audit trail, login history, and role-based access control. The results of the identification process are listed in Table 6.

Table 6 Comparison of Content Management Systems

Characteristics	PHP Nuke	DotNetNuke 5.0	SharePoint 2007	Oracle Portal 10	Websphere EIP 8
Openness					
Able to interface with technologies used in rehabilitation	Yes	Yes	Yes	Yes	Yes
Able to interface with electronic health records and database	Yes	Yes	Yes	Yes	Yes
Extensible					
Able to meet with TR requirements, including:					
Provide support for online data management	No	Yes	Yes	Yes	No
Provide asynchronous collaboration tools	Limited	Yes, but some modules cost	Yes	Yes, but some modules cost extra	Yes, but most modules cost extra
Provide management of workflow	No	Yes, but module cost	Yes	No	Yes, but module cost
Provide ability to share information	Yes	Yes	Yes	Yes	Yes
Can be customized to fit into TR setting	Yes	Yes	Yes	Yes	Yes
Can be accessed anywhere, anytime	Yes	Yes	Yes	Yes	Yes
Scalable					
Easy to add more modules to the system	No	Yes	Yes	Yes	Yes
Easy to add more users to access the information	Yes	Yes	Yes	Yes	Yes, but might cost extra
Cost-effective					
Cost of procurement	$0	$0	$4k	$10k	$10k
Security					
Audit trail	No	Limited	Yes	Yes	Yes
Login History	No	Yes	Yes	Yes	Yes
Role-based Access Control	No	Limited	Yes	Yes	Yes

Source: cmsmatrix.org

The first candidate, PHP-Nuke, depended on the developer's ability to create most of these tools themselves or procure the tools from other sources. The main focus of this open-source project was only to develop the main infrastructure for a CMS. DotNetNuke, on the other hand, has more features already built-in with the package. However, DotNetNuke had limited capability to meet the security requirements. DotNetNuke also required developers to build or procure some asynchronous collaboration tools themselves, including tools to develop online forms and tools to track service workflow. On the other hand, Microsoft Sharepoint, Oracle Portal, and IBM Websphere EIP could met all the requirements without having the developers build or procure asynchronous collaboration tools from other sources. However, Sharepoint had the lowest financial impact to deploy, as the cost of procurement was the lowest and the package came with all components required to support asynchronous collaboration, with no hidden extra costs.Based on the result of the exploration process, Microsoft Sharepoint was selected as the foundation to build the CMS component of the integrated system. The deciding factors in this decision were the completeness of the modules in the package and the ease of customizing the system to fit into TR. The combination of these two deciding factors resulted in a minimal amount of effort required to interface the CMS into the integrated system. In addition, a lot of metropolitan healthcare facilities already used Sharepoint in their organization, thus nullified the financial impact from procuring the CMS itself.

4.5 MATCHING THE NEEDS AND TECHNOLOGIES

All the technologies previously identified were validated against the identified requirements to ensure a proper fit of the integrated system in RWP. The validation process explored all activities and documents from traditional wheelchair prescription service in face-to-face setting and ensured that an IT component to transform those activities and documents existed in the integrated system. The two primary technologies for the integrated system were:

- A videoconferencing technology which was used as the IT component to provide real-time remote interaction (remote-synchronous collaboration)

- An online portal developed on top of a CMS technology which was used as the IT component to host task management, document and data management, non-real-time communication (such as electronic messaging and forum discussion), and access to archive of sessions. This component is necessary for communication, coordination, and managing all the information throughout TR (remote-asynchronous collaboration)

The result of the validation process is a matrix of IT components and requirements (Table 7). This matrix allowed tracking of the tools given to each team members of the multidisciplinary team during each phases of the workflow in RWP. Using this matrix, the user interface for the integrated system can be optimized to provide access only to necessary tools that the users need to complete their tasks. This approach reduced the complexity of the user interface, which increased the efficiency and the general usability of the integrated system.

Table 7 Matrix of Requirements, IT Components, and Data Type

Phase	Roles	Integrated System							
		Videoconferencing		Online Portal					
		Real-time Comm. And Interactivity	Data/ Document Sharing	Workflow	Data Mgmt.	Asynch. Colla-boration	Type of Info To Share: Regular Data Set	Multimedia data	XML-based Data
Initial Data Collection	Physician			Access to 1st Phase	Client Intake Form	Forums, email	Health status data		
Data Document.	General. Clinician	Video and Audio		Access to 2nd Phase	Client Intake Form	Forums, email	Health status data, Functional Assessment Data	Assessment video	Device specs
					Demo-graphic Form Pre		Demo-graphic data	Environment video	
					FEW Form Pre		Client's perception		
	Expert Clinician	Video and Audio	Assessment guidelines	Access to 2nd Phase	Client Intake Form	Forums, email	Compilation of client data	Assessment video	Device specs
			Device specs						

Finalizing Document.	RTS			Access to 3rd Phase	Online forms	Email, IM	Home Assessment Data	Home Model	Device specs
	General. Clinician			Access to 3rd Phase			Compilation of client data		
	Physician			Access to 3rd Phase	Client Intake Form	Forums, email	Compilation of client data		
Device Fitting / Delivery	General. Clinician		Device Specs.	Access to 4th Phase	Online forms	Email	Compilation of client data	Assessment video	Wheelchair specs
	Expert Clinician			Access to 4th Phase	Client Intake Form		Compilation of client data		

For example, during the data documentation phase (2nd phase in the workflow), the generalist clinician would need to communicate in real-time with the expert clinician during an assessment. The expert clinician might need to share some assessment guidelines and/or potential assistive technology device specifications that match with the client's condition and needs. After the assessment has been concluded, the generalist clinician would need to document the client's condition. The expert clinician would also need an access to the same document and provide feedbacks to the generalist clinician. The expert clinician might want to use email to send this feedback. The feedback might then trigger a discussion between the generalist and expert clinician, where they would need to share and re-visit some of the information about the client and the record of the assessment session. With this matrix, developers could check back on all the requirements of the 2nd phase and ensured that the integrated system would have a specific component that provided the proper support to meet the requirement. Continuing with the previous example, developers could check that during 2nd phase, the videoconferencing component would support the need of real-time video and audio conferencing between the generalist clinician and the expert clinician. The videoconferencing component would also support the expert clinician to share the assessment guidelines and the device specifications. Afterward, the online portal would support the documentation process by providing the access to the necessary documents, including client intake form, demographic form, and service satisfaction form. Any asynchronous collaboration activities would also be supported by the online portal through the use of email and discussion forum. The online portal would also store and allow sharing of client's information, including information on client's condition, device recommendation, and also the recorded assessment session.

4.6 SUMMARY

Two primary activities were conducted during the verification phase for the integrated system: identification of needs and identification of technologies. In the identification of needs, the verification phase explored the workflow of traditional wheelchair prescription service in face-to-face setting, performed analysis of roles to identify the information requirements for each person in the service identified phases and activities within the service, and identified the types of collaboration support required to complete the service. Afterwards, the findings were brought into a 'tele' setting, which transformed the activities to fit into TR.

In the identification of technology, the verification phase explored technologies required to develop the IT components for the integrated system to support the activities of RWP. The two types of collaboration, remote-synchronous collaboration and remote-asynchronous collaboration required a distinctive set of IT components. To support both types of collaboration, the study explored two types of technologies: videoconferencing and content management system. The technologies chosen were based on PITT Model's guiding principles (Saptono, Schein, Parmanto, & Fairman, 2009).

Afterward, the identified technologies were validated back to the system requirements. The result of this process is a matrix of workflow and IT components containing the type of information required for successfully completing each phase within the workflow.

The result of the verification phase is essential in designing and developing the system to support RWP, further discussed in Chapter 5.

5.0 DEVELOPMENT OF VERSATILE AND INTEGRATED SYSTEM FOR REMOTE WHEELCHAIR PRESCRIPTION

5.1 REMOTE WHEELCHAIR PRESCRIPTION

The remote wheelchair prescription project (RWP) required an integrated system to support collaborations for delivering the wheelchair prescription service over the distance (as previously discussed in chapter 4). To support this project, the Rehabilitation Engineering Research Center on Telerehabilitation (RERCTR) designed, developed, and customized an integrated system called VISYTER, which is an abbreviation of the Versatile and Integrated System for Telerehabilitation. This chapter discusses the process of designing, developing, and fitting VISYTER into RWP. The process followed closely with the guiding principles derived from the PITT model. Although the process described in this chapter mainly focuses on RWP, the methodology can be used in any application of TR.

Three information technology (IT) components were required to support the TR services: videoconferencing, online portal, and database. During the verification process, four roles were also identified as the main ‘actors’ of the service: expert clinician, generalist clinician, physician, and rehabilitation technology supplier (RTS). Figure 7 illustrates the conceptual collaboration flow of RWP, supported by the three IT components.

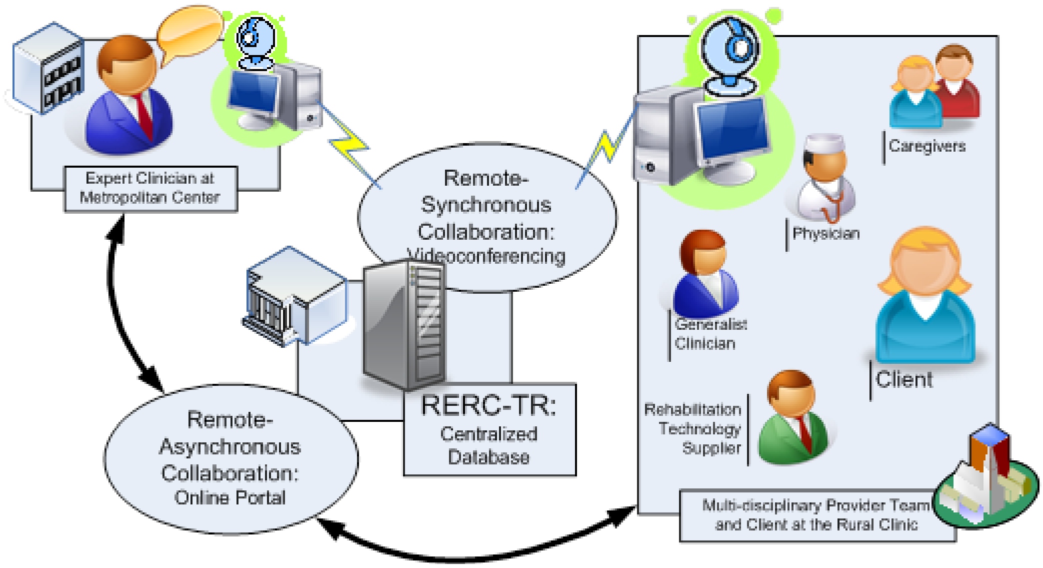

Figure 7 Remote Wheelchair Prescription Conceptual Collaboration Flow

In synchronous collaboration, the focus was on the use of the videoconferencing system to provide a real-time teleconsultation between the expert clinician in a metropolitan area center with the multi-disciplinary team in a rural area clinic, consisting of a physician, generalist clinician, and RTS. To protect the confidentiality of the teleconsultation session, the communication channel had to be secure. In addition, the RWP required a capability to archive any session into the centralized database for later review.

In asynchronous collaboration, the focus was to complete the documentation process for creating a mobility device recommendation for the client. The process required the multi-disciplinary team to work together from multiple places at different times. For example, home assessment was usually conducted by RTS after the teleconsultation session. The home assessment information was then sent to the generalist clinician and was used to assist in finalizing the documentation needed for the mobility device recommendation. The expert clinician would be consulted afterwards to ensure that the information within the recommendation was correct and complete.

5.2 DESIGNING VISYTER

The aim of VISYTER's design process was to create a blueprint for development and customization phases. This design was based on the requirements identified in the verification process. Based on the PITT model, the process focused on the creation of four designs: integrated system design, component-system interfaces design, security design, and customization plan.

5.2.1 Design of Integrated System

RWP had a unique IT dynamic: any group of roles conducting a remote-synchronous collaboration required a real-time access to the remote-asynchronous collaboration tools. For example, during a teleconsultation session, the generalist clinician might need to retrieve or store client information from or into the database. On the contrary, any role performing remote-asynchronous collaboration tasks did not need access to the remote-synchronous collaboration tools. However, RWP required that any remote-asynchronous collaboration task could be completed from anywhere, anytime. This dynamic directed the design of two separate access points into VISYTER. First, individuals could access VISYTER's desktop application to support any remote-synchronous collaboration, which was comprised of both the videoconferencing and CMS components. Second, individuals could access VISYTER's online portal directly using any Internet browser to perform their asynchronous-collaboration tasks. Figure 8 illustrates the dynamic access design of VISYTER.

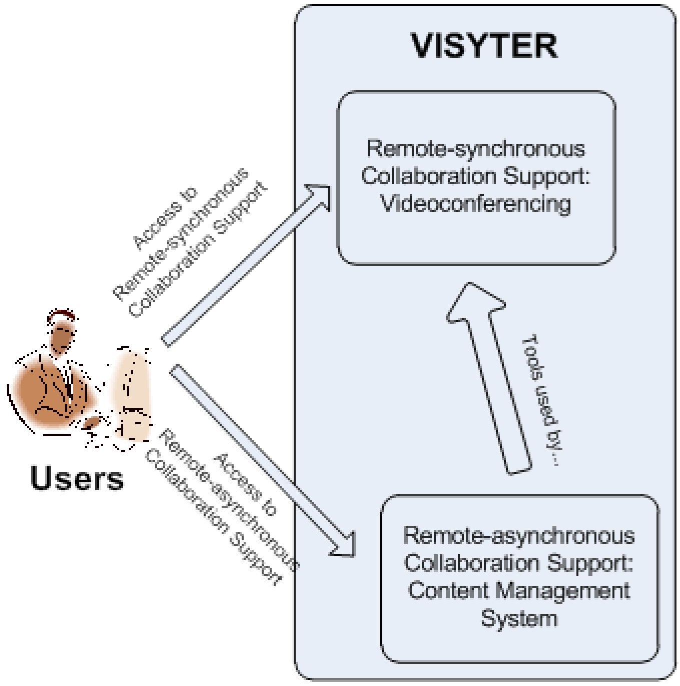

Figure 8 Dynamic of VISYTER Access Points in Remote Wheelchair Prescription

Remote-Synchronous Collaboration Tool Design

The focus of the design for the remote-synchronous collaboration support tool was to create a simple and intuitive interface for smooth videoconferencing experience in TR. Simplicity in the interface denoted uncluttered, elegant interface in which important features of the system were placed in an orderly fashion and could be seen directly, not hidden behind other, less important interface elements. Intuitive signified the ease of learning and remembering how to find and operate the features of the system without an extensive training. With these two aspects properly attended, the videoconferencing experience was expected to be smooth, allowing individuals to focus on communicating and less on figuring out how to use the system itself.

The idea of integration led the design to favor on a single window approach to host all the interactivity modules instead of using multiple floating windows for each interactivity module. This single window approach provided users with an easier access to the collaboration tools and reduced the confusion of having to manage multiple windows during remote-synchronous collaboration. Figure 9 illustrates the design of VISYTER's graphical user interface (GUI) with single window approach. In this design, all important features of the system could be seen directly and could be accessed in one-click. In addition, the design mimicked common user interface from well-known Microsoft Office applications, such as Microsoft Word and Excel.

This approach allowed the system to utilize individuals' prior experience with these applications, thus reducing the amount of time required to learn and familiarize with the interface.

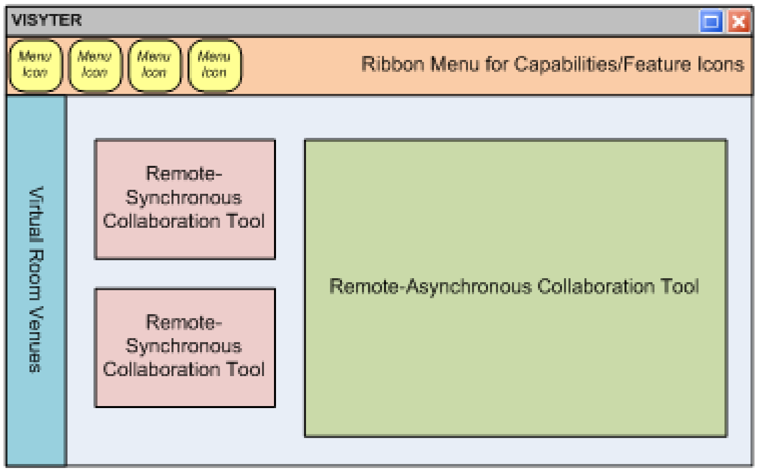

Figure 9 Design of Integrated Videoconferencing System with Single Window Approach

Three types of components was used to build the remote-synchronous collaboration support tool: standardized components from third-party developers that is used without modification, components modified and customized from open-source projects, and components developed in-house by RERCTR team. Figure 10 depicts the layers of components to build the remote-synchronous collaboration support.

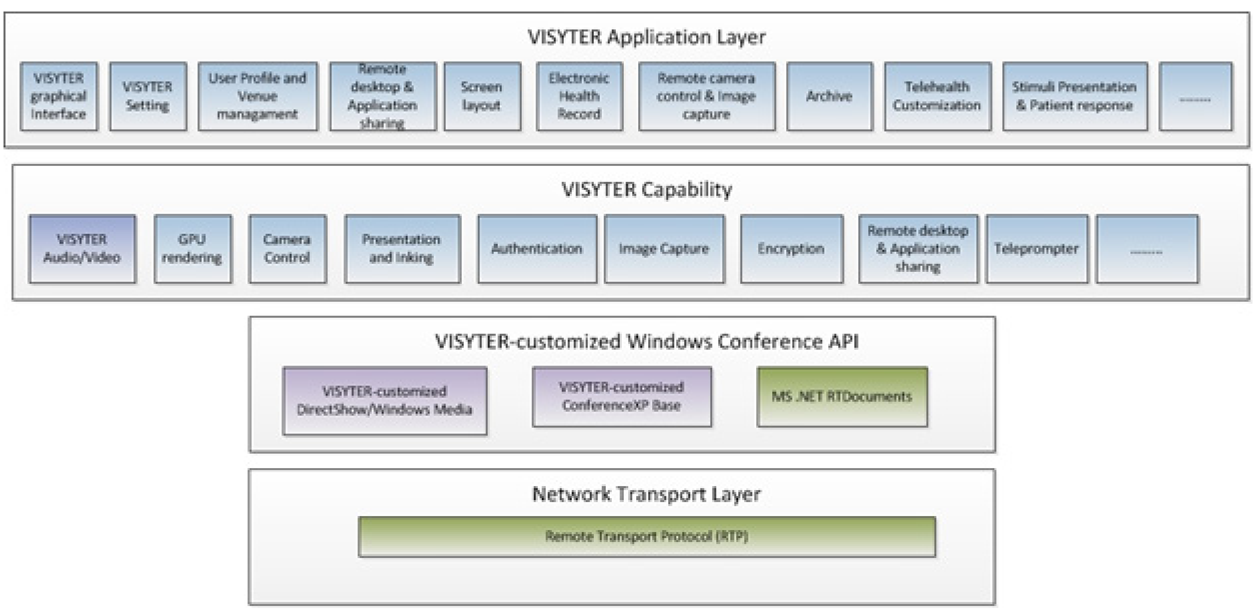

Figure 10 Remote-synchronous Collaboration Application Layers

The remote-synchronous collaboration support is comprised of four layers: network transport, windows conference API, capability, and application. The network transport layer is the lowermost level, which deals directly with the network. In this layer, VISYTER utilized standardized Remote Transport Protocol (RTP) which allows any communication packets to be transferred via the Internet in a burst. The protocol was implemented in an open-source component and was used as-is; this component was not modified by the RERCTR team. In the picture, this type of component is depicted with a green box.

The second layer on top of the network transport is the Windows Conference API. This layer was built to interface the network with the remote-synchronous collaboration support that runs on top of Microsoft Windows operating system. VISYTER adopted components from open-source videoconferencing projects to build the foundation of the remote-synchronous collaboration support. These components are depicted in the picture with a purple box. In this layer, VISYTER adopted DirectShow/Windows Media component and real-time interactivity component from ConferenceXP. Both components were customized by the RERCTR development team to fit into TR. The first component (DirectShow) was responsible to manage the video and audio stream, and was modified to be able to adapt to any bandwidth limitation. The second component (ConferenceXP base/real-time interactivity) was modified to be able to fit into any equipment used in TR, including tablet display, slate computer, and netbooks. VISYTER also used Microsoft's implementation of RTDocuments, which is used primarily to share stimuli presentation across sites.

The third layer and the fourth layer of VISYTER's remote-synchronous collaboration support work hand-in-hand. The third layer is the VISYTER Capability layer, which houses the core functionalities of VISYTER. The fourth layer (Application) wraps these core functionalities into applications that can be used by VISYTER's user. For example, Screen Layout (Application layer) allows user to automatically adjust the size and placement of VISYTER Audio/Video, presentation, and teleprompter (Capability). Most components on these layers were developed in-house by the RERCTR team, and are depicted in blue box in the picture.

An example of a tool that was designed and developed in-house was remote camera control. The camera control tool was required by expert clinician to adjust the remote camera’s viewing angle without interrupting the flow of the assessment conducted by generalist clinician. Figure 11 illustrates the schema of the camera control. With this tool, expert clinician could change the camera viewing angle by clicking on a button inside the camera control panel. This click is translated into a control command, which would be sent through a sender module via the Internet, and received by a receiver module at the remote site. The receiver module utilized the operating system's Application Programming Interface (OS API) and the camera's driver to translate the control command into a low-level machine protocol to control and move the camera. This design allowed a user to control multiple cameras or multiple users to control a single camera.

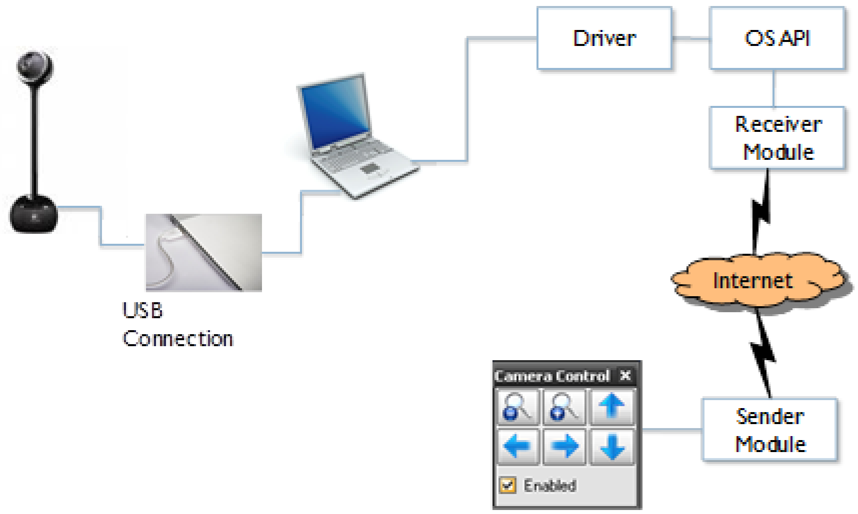

Figure 11 Remote Camera Control Design

<u>Remote-Asynchronous Collaboration Tool Design</u>

Based on the verification phase, an online portal built on top of CMS has been identified as the best option to develop the remote-asynchronous collaboration component. Online portal could serve as a platform to centralize documents and information from various sources. Infusing the PITT model in the development of the online portal enabled the creation of a remote-asynchronous collaboration support that was open, extensible, scalable, secure, and cost-effective. Figure 12 illustrates the concept of online portal for VISYTER.

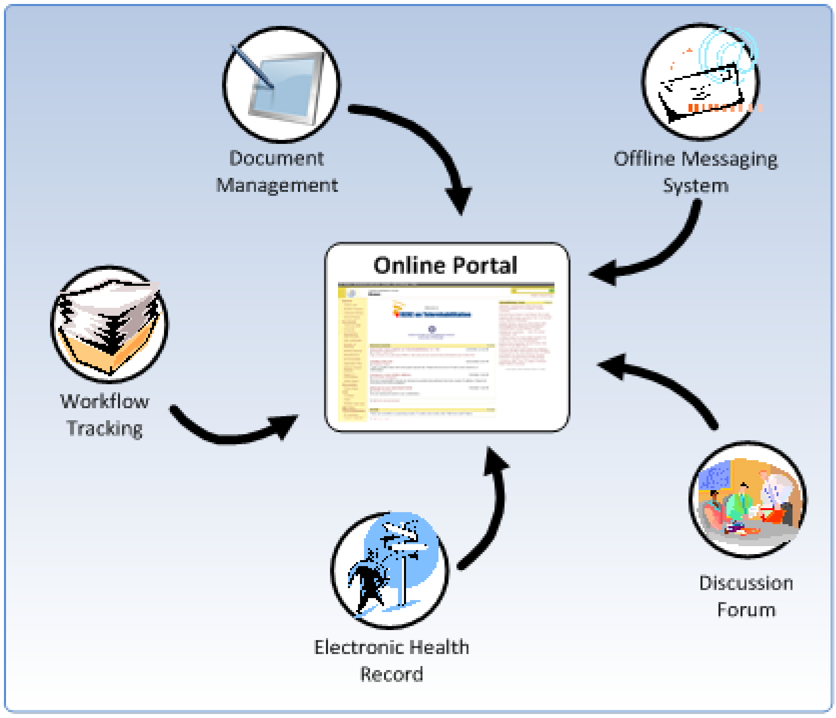

Figure 12 Modular Concept of the Online Portal

The online portal allowed integration of cost-effective remote-asynchronous collaboration tools developed by various sources: internally by RERCTR, open source community, and even third-party developers. Some examples of these tools were: document management tool, task/workflow tracking tool, discussion forum, messaging system, and electronic health record. The online portal was extensible, allowing these customized tools to be 'plugged-in', similar to Lego blocks, to build a sophisticated remote-asynchronous collaboration platform that conformed to RWP's needs. Additional online portals could be created easily from templates derived from previously built portal, making the platform scalable to serve any demands from the project. Access to the online portal was secured to protect the confidentiality and integrity of the information stored within. The security mechanism consisted of the use of authentication protocol, role-based access rules, and multiple layer of protection. This mechanism is detailed further at section 5.2.3.

SharePoint CMS technology was chosen as the technology to build the online portal. This technology allowed the creation of highly customized online portal for each user. The portal's features can be customized based on the user's role in the project. For example, the portal may provide individualized calendar and scheduling system for each user. A generalist clinician can use this calendar to view an expert clinician's availability when scheduling a teleconsultation session. Furthermore, SharePoint also provided a mechanism to limit user's access to information based on their roles in the project. For example, a generalist clinician may have a portal that provided access only to their clients, while the expert clinician may have a portal that provided access to all clients. Figure 13 illustrates the concept of interconnectivity between portals for VISYTER.

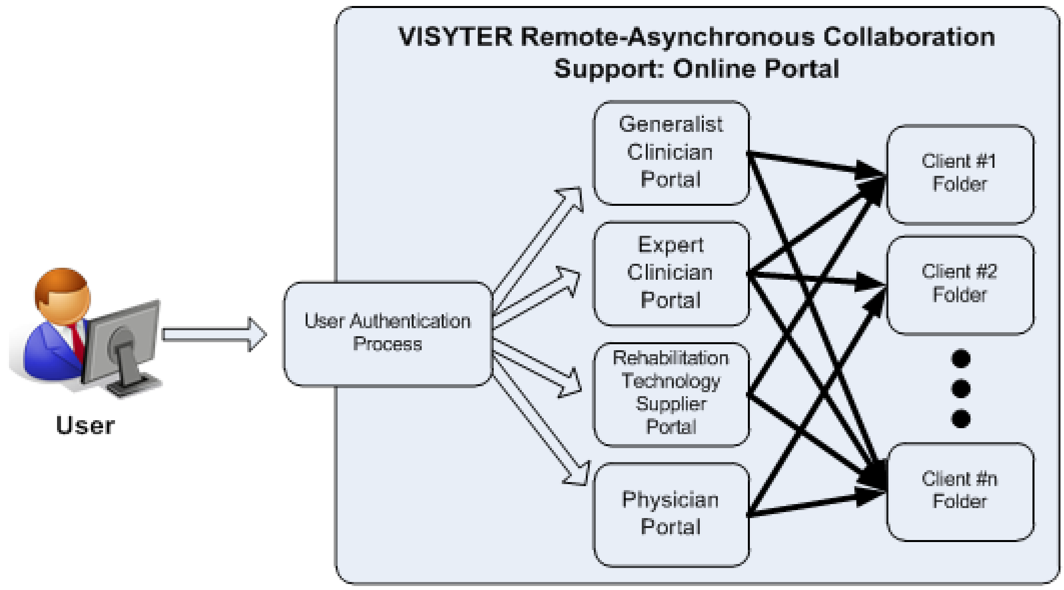

Figure 13 Design of Portal Interconnectivity

Based on this design, two types of portals were required to support the remote-asynchronous collaboration: service provider portal and client folder. The service provider portal was designed to grant access to personal workspace for the RWP's multidisciplinary team members, and was equipped with features to track their personal tasks, including calendar, links to client information, document storage, and links to online resources. In Figure 13, all portals in the middle column (physician portal, generalist clinician portal, expert clinician portal and RTS portal) fall into the service provider portal category. The client folder served as the information integrator to support the interaction between RWP's multidisciplinary team members, the client, and/or caregivers. This folder was equipped with features to monitor each individual client's service, such as service progress tracker, client document storage, and links to consumer-health online resources. In Figure 14, all folders in the right column (Client folder #1 to Client folder

#n) fall into the client folder category. Figure 58 illustrates the GUI design for the service provider portal and the client folder.

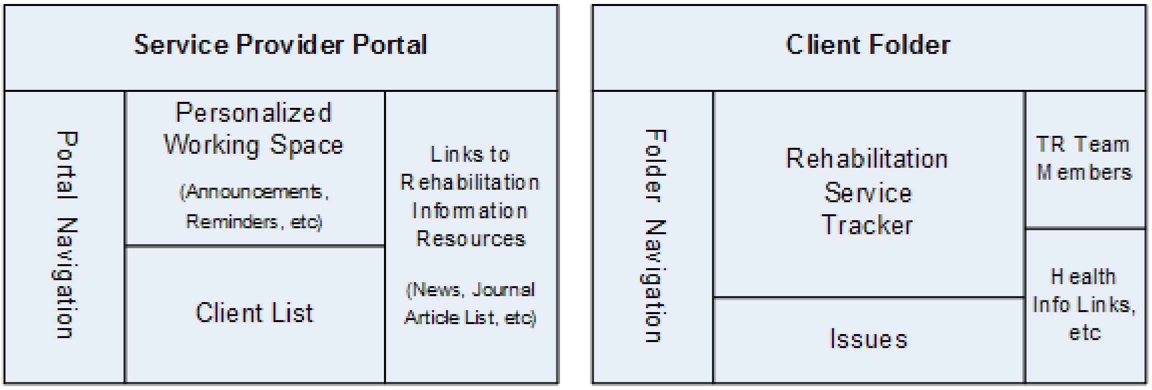

Figure 14 Design of Service Provider Portal and Client Folder

5.2.2 Design of interfaces between IT component, System, and Database

The two collaboration types in RWP required access to a different set of IT components. The remote-synchronous collaboration required access to IT components that provided real-time interactivity and real-time information. On the other hand, the remote-asynchronous collaboration required access to IT components that provides document management, and process tracking. The unique dynamic of RWP also required real-time access to the information stored inside the remote-asynchronous collaboration tool during a remote-synchronous collaboration. Therefore, the design of interfaces for VISYTER to support RWP was divided in three: interface for remote-synchronous collaboration, interface for remote-asynchronous collaboration, and interface to bridge the information from the remote-asynchronous to remote-synchronous collaboration (Figure 15).

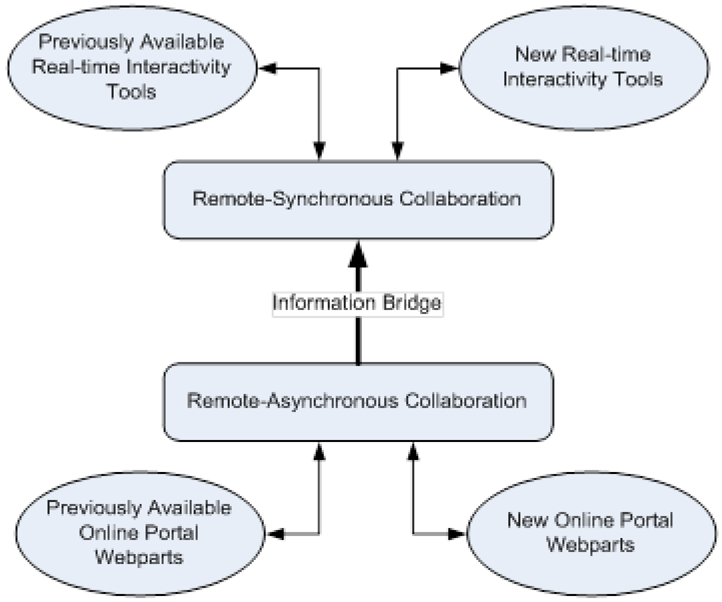

Figure 15 Interfaces and Bridges for VISYTER

Designing the Interfaces for Remote Synchronous Collaboration

The single window approach for the remote-synchronous collaboration required extensive customization to integrate all previously developed remote-synchronous collaboration tools into a single system. Several tools were adopted from open source videoconferencing projects, such as ConferenceXP. These tools include multimedia streaming, interactive whiteboard, and session archiving. However, because most of these tools were originally designed for classroom presentation in multiple windows approach, an interface to integrate and access the tools from a single window was required to be present in VISYTER. The interface consisted of two main components: a single, main window which acted as the host to display the tools, and a ribbon menu that hosts icons to access the tools (Figure 16). In addition, VISYTER developed a specific directive to force the creation of any tool inside the main window instead of spawning the tool as a separate window outside the main window.

Figure 16 Ribbon Menu and Menu Icon

Designing the Interfaces for Remote-Asynchronous Collaboration

SharePoint allowed the addition of different remote-asynchronous collaboration tools into the online portal in the form of webpart, a small, modular module that can be interchanged between portals. The webparts allowed customization of the online portal based on RWP's needs. SharePoint came with several standard webparts, such as discussion board, document and folder management, task list, and workflow management. These standard webparts required no interface bridge to add into the online portal.

Beyond the standard webparts, RWP required a webpart to provide online forms. Online forms were used to store client's information in electronic format. SharePoint had a standard survey webpart, which was commonly used to create online forms. However, the survey webpart did not have the sophistication required by RWP. To provide the online forms for RWP, VISYTER utilized form webpart provided by InfoPath 2007, one of the tools offered though Microsoft Office Suite 2007. InfoPath 2007 has the capability of producing electronic forms and publishing the electronic forms into SharePoint, transforming these forms automatically into online forms (Figure 17). The data was then stored within SharePoint as a document, which could be accessed through the document and folder management webpart.

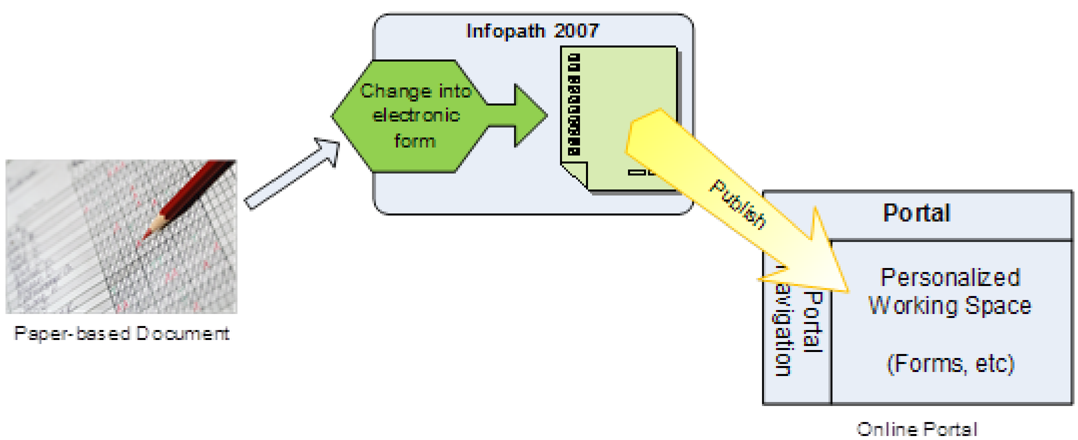

Figure 17 InfoPath: Moving Paper-based Document into Electronic Forms in Online Portal

Designing the Interfaces to Bridge the Remote-Synchronous and Remote-Asynchronous Collaboration

VISYTER required a bridge to interface between the remote-synchronous and the remote-asynchronous collaboration to conform to the IT dynamic of RWP. The bridge to interface the two types of collaboration was split into two parts: interface in the remote-synchronous collaboration tool and interface in the remote-asynchronous collaboration tool.

An integrated Internet browser was developed as the interface in the remote-synchronous collaboration tool. When initialized, the Internet browser window sent login information to the online portal through an encrypted channel. Once authorized, the Internet browser automatically activated the user's personalized online portal. The user could afterward browse through the portal to access client information seamlessly during the remote-synchronous collaboration.

The interface in the remote-asynchronous tool was in the form of a web-based form authentication page. The web-based form authentication page received the login information from the remote-synchronous platform, authenticated the information against the portal's user management system, and, once authenticated, redirected the page into the user's personalized portal page. The personalized portal page was sent back to the remote-synchronous tool, where the user had access to any information inside their personalized portal page.

Figure 18 illustrates the flow of interaction between the Remote-Synchronous and Remote-Asynchronous component of VISYTER for RWP.

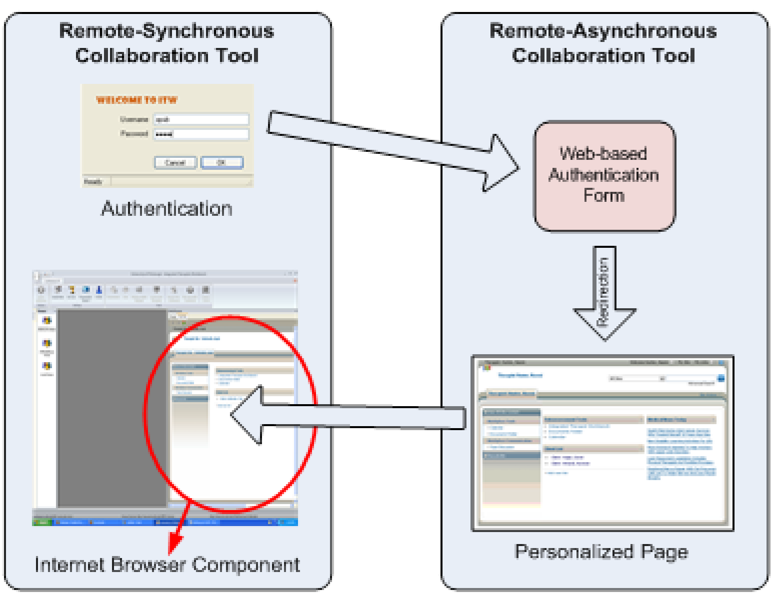

Figure 18 Interfacing Remote-Asynchronous Collaboration to Remote-Synchronous Collaboration Tool

5.2.3 Design of security

VISYTER employed three layers of security to protect the confidentiality and integrity of the information: user authentication, encryption, and role-based access limitation to documents (Figure 19).

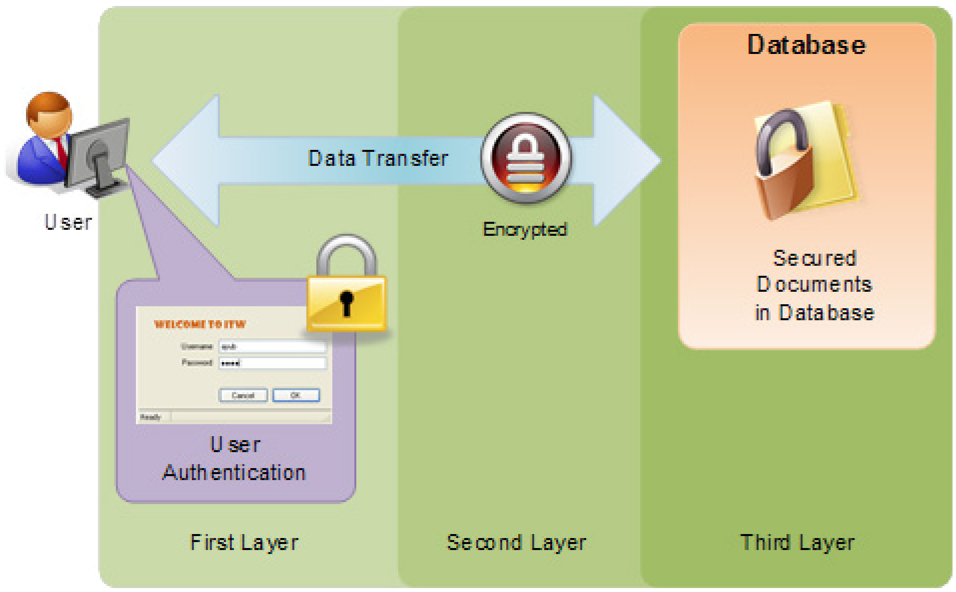

Figure 19 Layers of Security in VISYTER

The first layer of security was user authentication. The user authentication was based on the Lightweight Directory Access Protocol (LDAP), and integrated with the online portal through the use of a secure web-based authentication form. This method allowed VISYTER to authenticate users accessing during both remote-synchronous and remote-asynchronous collaboration.

The transfer of any information through the Internet network was secured by using the second layer of security: encryption. Currently, the encryption was done through compression and shared single digital key method. With compression, not only data can be streamed in a lower bandwidth requirement, the data was also protected from information tapping. VISYTER was also designed with the capability of encrypting any data stream using Secure Socket Layer (SSL) protocol. To use SSL, RERCTR issued a security certification for encrypting any information streaming from and into the RERCTR's network, including username and password, video and audio stream, and client information.

The third layer of security was in the form of role-base access limitation to documents. The access limitation ensured that users can only access the specific information required to successfully complete their task. The access limitation was based on the user's role in the service. This layer of security also increased the usability of VISYTER as well, because users were not overflowed with superfluous information unnecessary to complete their tasks.

5.2.4 Design of Customization Plan: Transforming Wheelchair Prescription Workflow

Wheelchair prescription service at the Center for Assistive Technology within the University of Pittsburgh Medical Center (CAT-UPMC) followed a comprehensive standardized guideline to ensure that clients received appropriate wheeled mobility and seating devices according to their needs. To support RWP, VISYTER was required to implement the same standardized guideline, customized for use in telerehabilitation (TR). The process of customizing the standardized wheelchair prescription workflow for TR utilized the following guidelines:

I. *Removal of automated steps.* Removal of steps to be automated from the workflow was necessary to simplify the traditional workflow. A step can be automated if it did not require an active intervention from a human component to finish the task. For example, the process of confirming a letter of medical necessity required the clinician to manually confirm the letter (such as by pressing a button, or adding digital signature into the document), thus this step could not be removed from the workflow. On the other hand, the process of clinician sending documents to RTS could be automated by the use of online portal (which practically eliminated the need of sending the document).

II. *Identify the role responsible for the step.* Previously, four roles have been identified and described within the remote wheelchair prescription project: generalist clinician, expert clinician, physician, and rehabilitation technology supplier. Tying the role with the steps allowed the creation of:

- Role-controlled workflow. Every person had a role in the project, and every role had a specific responsibility according to the workflow.
- Tracking system. Clinicians can monitor the progress of the service delivery for each client by looking at the workflow progression.

- Reminder system. The online portal also provided an alert system with automated messages to remind each role of their responsibilities to advance the service progression.

III. *Identify the information managed in the step.* Identifying the type of information managed in each step assisted with identifying what types of documents are associated with each step. For example, in the initial assessment, client's data such as demographic information and health status data were collected by generalist clinicians. Therefore, to manage this type of data, VISYTER allowed generalist clinician to access the client intake document in this step.

IV. *Identify the type of IT component to support the step.* Several steps, such as assessment steps, required the use of remote-synchronous collaboration tools to connect the generalist clinician with the expert clinician. The documentation phase; however, focused more on managing the information which primarily required the online portal. The workflow became a guiding tool for clinicians, providing access to particular documents necessary to perform and complete any particular phases within the workflow.

The result of this process was a matrix of steps, responsible roles, supporting documents, and IT components for each phase within the RWP workflow:

Table 8 Matrix of Steps, Responsibility, and Information Requirements

	Role	Step Name	Document Associated	IT Components
Phase 1 Initial data collection				
01	Physician	Initial Assessment	Client Intake Document	Online portal
Phase 2 Data documentation				
01	Gen. Clinician	Client's Demographic Information Collection	Demographic Data - Pre	Online portal
02	Gen. Clinician Exp. Clinician	Initial Assessment	Client Intake Document	Online portal Videoconferencing
03	Gen. Clinician Exp. Clinician	Functional Assessment	Functioning Everyday with Wheelchair Form - Pre	Online portal Videoconferencing
04	Gen. Clinician Exp. Clinician	Device Trial	Client Intake Document	Online portal Videoconferencing
Phase 3 Finalizing the documentation				
01	RTS	Home Assessment	Client Intake Document	Online portal
02	Gen. Clinician	Review Client Information	Client Intake Document	Online portal
03	Physician	Approve Recommendation	Client Intake Document	Online portal

Phase 4 System delivery/fitting				
01	Gen. Clinician Exp. Clinician RTS	Device Delivery and Fitting (assessing device customization)	Client Intake Document	Online portal Videoconferencing
02	Gen. Clinician Exp. Clinician	Final assessment	Functioning Everyday with Wheelchair Form - Post	Online portal Videoconferencing
03	Gen. Clinician	Demographic Data Post Service	Demographic – Post Form	Online portal
04	Gen. Clinician	Telerehabilitation Questionnaire	Survey Document	Online portal

5.3 DEVELOPMENT AND CUSTOMIZATION OF VISYTER FOR RWP

As previously mentioned in chapter 3 (3.4.2 Design and Development Phase), the development process consisted of three steps: development of prototype, prototype customization, and optimization. The development process of VISYTER for RWP was done through multiple iteration cycle of these three steps. However, the process and its results are presented in a linear fashion as to reduce any confusion in understanding the development effort.

5.3.1 Development of prototype

The process of developing the prototype for both remote-synchronous and remote-asynchronous collaboration was divided in four key steps:

1. Creation of the core of the prototype using the proper IT component based on the design
2. Creation of modular tools based on identified requirements
3. Weaving tools into the prototype through interfaces
4. Result testing to prune bugs and errors

Database technology was used extensively in the prototype development process. The database stored the online portal, its structure and contents (including all numerical data, documents, and electronic forms), any session archived from videoconferencing sessions, and all authentication information. This database was located within a secure server in the University of

Pittsburgh's network that could only be accessed through a secure connection. Microsoft SQL Server 2005 was utilized to provide the database for VISYTER.

Development of the Online Portal to Support the Remote-Asynchronous Collaboration

As previously mentioned, SharePoint technology was chosen to build the online portal for VISYTER. In SharePoint, Microsoft's ASP.NET was utilized to dynamically generate all website pages for the online portal. Therefore, the process of building the online portal started with installing both ASP.NET framework and SharePoint technology framework into the server. VISYTER utilized specifically Microsoft .NET Framework 3.5 and Microsoft Office SharePoint Server 2007 on a Windows Server 2003 with Internet Information Services (IIS) webserver.

Once installed, any website created on the IIS can be converted into an online portal by extending the SharePoint's framework into the website. VISYTER required two types of online portal: clinician's personal portal and client's folder. Two specific portal templates were developed and stored within SharePoint’s framework. These templates can be utilized to generate specific online portal whenever new clinicians or clients were added into the service. Afterward, a redirector was developed to guide users into their personal portal after authentication process.

Originally, SharePoint used native integrated windows authentication process on top of NT LAN Manager (NTLM) or Kerberos protocol to manage user login and access into the portal. However, VISYTER could not use this approach because of the limitation in interfacing the windows authentication process with the videoconferencing component. Therefore, developers opted to use a web-based form authentication method that allowed authentication from any applications through the use of SharePoint's web service. The web-based form authentication required a user management system in the form of LDAP to validate any access requests. VISYTER utilized Apache Directory Service, an open source LDAP technology to provide the required user management system.

SharePoint’s package came with several asynchronous collaboration components, including calendar, document folders, Really Simple Syndication (RSS) feed reader, list manager, workflow management, issue tracker, and discussion board. These components required minimal effort to plug into the online portal. Afterward, information about the RWP was added into the portal. For example, links to wheelchair-related rehabilitation online journal can be added to the list manager component to create a list of direct links to its articles. The workflow created in the design process can also be integrated into the portal using the workflow management and issue tracker components. Using these components, clinicians could track the progress of the service and identified any issues causing a delay for completion of any steps within the service delivery protocol.

SharePoint also came with an electronic survey/form component. However, this standard component did not allow an extensive customization of the form, which was required by RWP service. The first attempt to solve this limitation was to create an electronic form component, developed using Microsoft's ASP.NET technology. The component was lightweight and could be integrated easily into the portal. However, the amount of time needed to create even one electronic form was deemed to be too long for a dynamic service such as the RWP. This limitation led the investigation of a second solution, which was to utilize electronic form builder software and integrate the electronic form into the online portal. Microsoft InfoPath from Office 2007 was selected to provide this solution. The use of InfoPath reduced the amount of time needed to create a form. In addition, electronic forms can also be created by anyone familiar with the Microsoft Office 2007 technology, further increasing the versatility of the solution.

Figure 20 displays four screenshots of the online portal prototype: login/authentication page, workflow and document folder page, calendar page, and online form page. The login page is connected to the LDAP user management system. The workflow is used to provide access to document and online forms, and also to track the progress of rehabilitation service. The calendar page can be used to track clinician schedules.

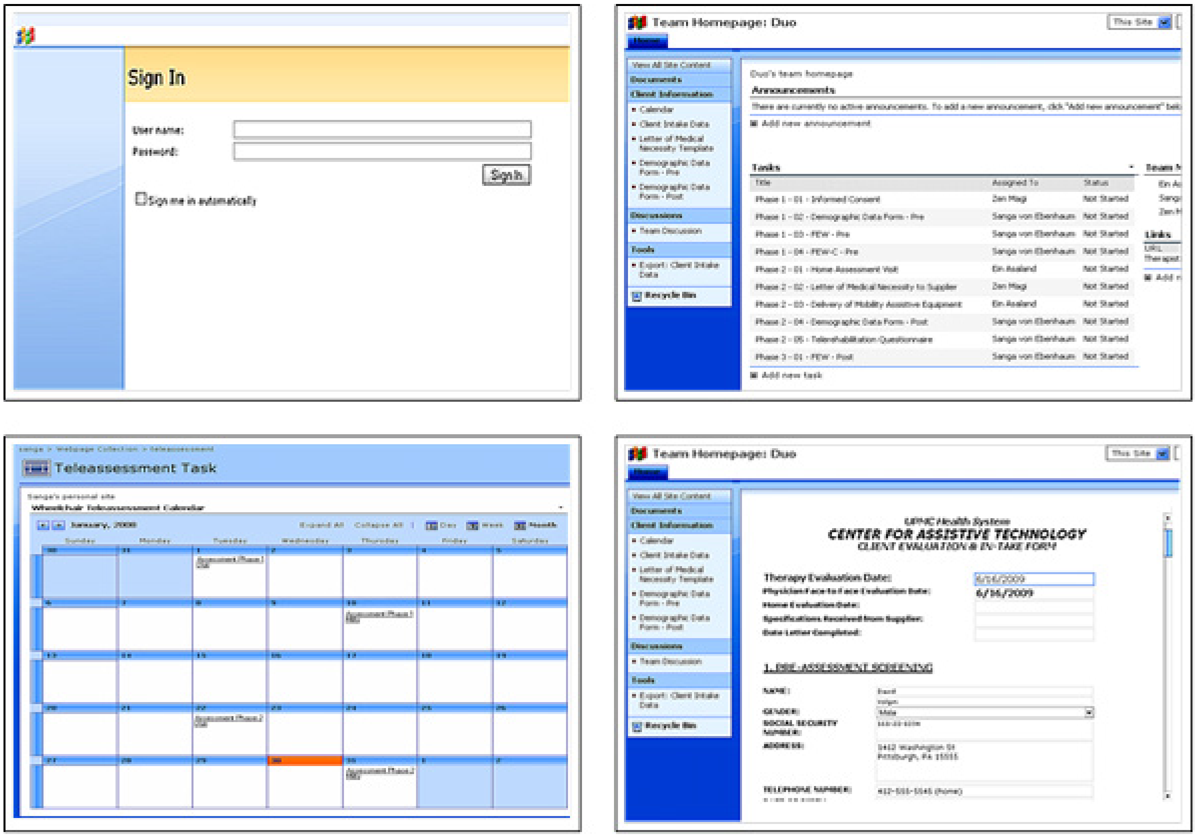

Figure 20 Remote-Asynchronous Collaboration Platform Prototype

Development of the VISYTER Prototype to Support the Remote-Synchronous Collaboration

VISYTER used videoconferencing components from open-source projects, including AccessGrid and ConferenceXP. ConferenceXP was originally developed by Microsoft Research, and its technology was based on the Internet2's AccessGrid, an open-source videoconferencing system project. Adopting open-source components into VISYTER required a deep and thorough investigation of all potential source codes to identify any components that can be transferred into VISYTER. Basic open-source components used in VISYTER include video/audio videoconferencing, text chat room, media streaming, presentation and whiteboard, and session archiving. In addition to basic open-source components, several components were developed and added into VISYTER, including remote camera control tool and tool to directly access information on the online portal in real-time. The camera control was based on chat room protocol.

Integration of online portal into VISYTER required a browser authentication component. Microsoft Internet Explorer was used as the browser component, while the authentication service on the portal server was developed using SharePoint's web service and LDAP technology. Once authenticated, the browser component retrieved and rendered the online portal content using a similar algorithm to a regular Internet browser.

Figure 21 shows the screenshot of VISYTER prototype. The first version of the prototype did not yet use the ribbon menu described in the design process previously. Instead, the prototype only used simpler interface consisting of top menu bar and the left control buttons.

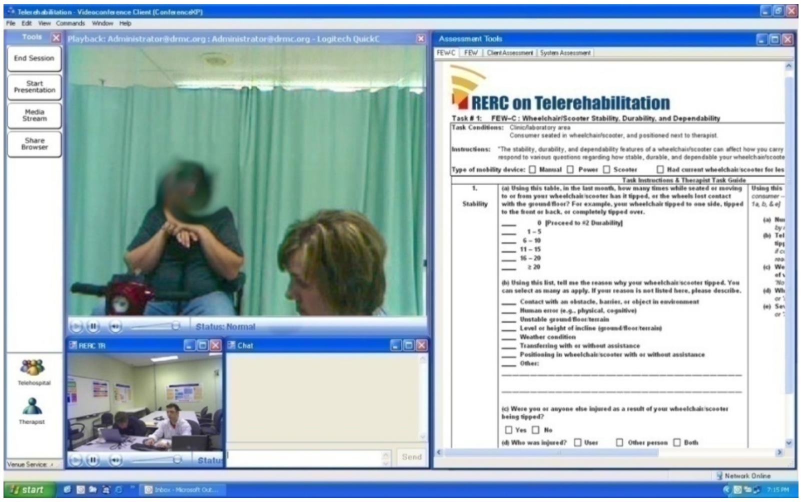

Figure 21 VISYTER Prototype

5.3.2 Customization of Prototype

Customization of prototype started after the process of testing and 'debugging' (identifying and correcting any errors in development). In customization phase, the customization plan designed in chapter 5.2.4 was followed to fit VISYTER prototype into RWP service. In addition, the GUI of VISYTER was refined to make it more aesthetically pleasing.

<u>*Customizing the Online Portal*</u>

Figure 22 illustrates the implementation of RWP workflow into the online portal. The workflow was client specific: each client had their own workflow, and only the service team members of the client had access to both the progress tracker and client information.

The workflow consists of phases and each phase requires a clinician to complete a specific document/form. Role-based access control was used by assigning user's roles in editing documents in the workflow. For example, physician can only edit documents related to Phase 0 (Initial Assessment) and Phase 2-03 (Approve Recommendation) of the workflow. The workflow would not continue until all documents/forms are completed. For example, to complete phase 1, the clinician has to complete several forms, including the Client Intake Document, FEW-Pre, and Demographic Data – Pre.

Using the workflow, clinicians were able to track the status of the service delivery and to access information through the Internet.

Workflow Checklist

Title	Assigned To	Status
Phase 0 - Physician: Initial Assessment	Campbell, Roy	Completed
Phase 1 - 01 - Therapist: Initial Assessment: Client Intake Document	Hunter, Naomi	Not Started
Phase 1 - 02 - Therapist: Functional Assessment: FEW - Pre	Hunter, Naomi	Not Started
Phase 1 - 03 - Therapist: Client's Demographic: Demographic Data - Pre	Hunter, Naomi	Not Started
Phase 1 - 04 - Therapist: MAE Trial: Client Intake Document	Hunter, Naomi	Not Started
Phase 2 - 01 - Supplier: Home Assessment: Client Intake Document	Emmerich, Hal	Not Started
Phase 2 - 02 - Therapist: Review Client Info: Client Intake Information	Hunter, Naomi	Not Started
Phase 2 - 03 - Physician: Approve Recommendation: Client Intake Information	Campbell, Roy	Not Started

Figure 22 Workflow and Telerehabilitation Progress Tracker

Two customized color themes and layouts were developed to differentiate between the two types of portals (Figure 23). The clinician portal was developed with soft-red theme, while the client folder used soft-blue colors. The different colors were used to signify change of activities. In the clinician portal, all activities inside the portal were centered around the clinician, such as managing schedules and managing personal documents. When a clinician moved to the client folder, all activities in the portal were centered around the client, such as tracking client's TR progress and solving any issues. Thus, different color themes were used to signify the changing of all activities' focused in the portal: from clinician to client.

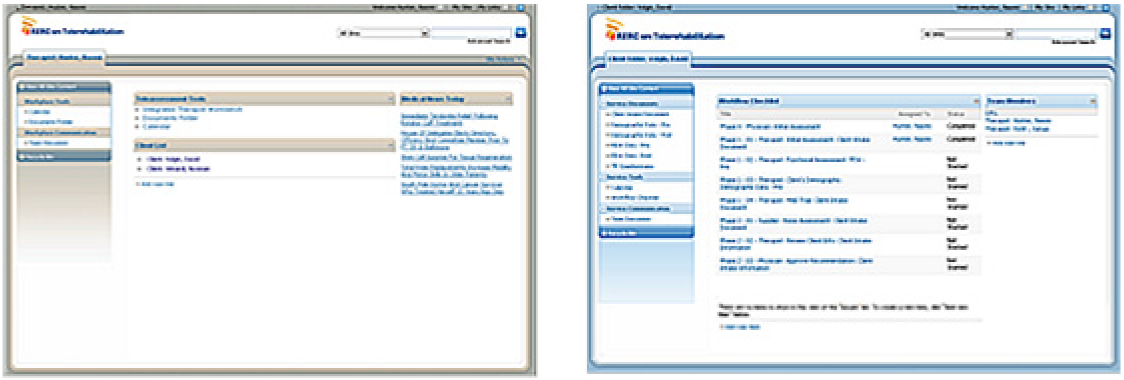

Figure 23 Customized Themes for Clinician Portal and Client Folder

Customizing VISYTER Prototype

VISYTER’s prototype required direct access to several documents on the online portal, including: Client Intake Document, Functioning Everyday with Wheelchair Form Pre and Post, and Demographic Form Pre and Post. As mentioned previously, access to these documents was provided by adding an Internet browser component to interface with the online portal. Although the browser component's behavior mimicked a regular Internet browser (i.e. Microsoft Internet Explorer), the component was not equipped with Internet navigational buttons, such as forward & back button, or home button. Thus, a simple navigational menu with Internet navigational buttons was added on top of the browser component. This customization allowed clinicians to navigate easily through the online portal.

The GUI of the integrated videoconferencing platform was also modified to use Microsoft Office 2007 windows styling theme. For example, instead of having a menu bar on the top part of the window, developer customized a ribbon menu and context-driven menu icons. The left part of the window, which contained a list of conference participants and the right part of the window, which contained the Internet browser component were configured to perform an 'auto-hide' function. The 'auto-hide' function allowed both parts of the window to slide out, providing bigger space to place video and audio conferencing components. This setting allowed clinicians to layout the videoconferencing windows according to the need of the session: additional personnel could be shown in the monitor during a session. Figure 24 shows some screenshots of the customized integrated videoconferencing platform.

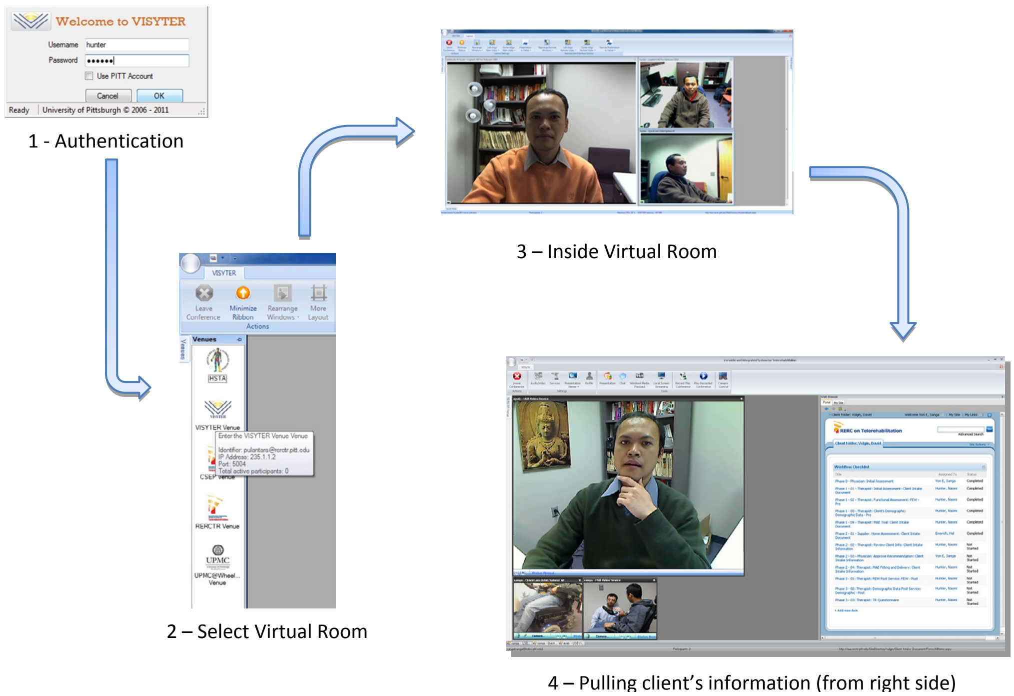

Figure 24 Customized Look of VISYTER Prototype

5.3.3 Optimization of Prototype

Optimization of the prototype required an understanding of the technological constraints from the remote clinics/sites. Based on the limitations identified in chapter 4 (4.2.4), VISYTER was packaged into a standardized installation with wizard to help automatically set up the VISYTER at any sites. In addition, a list of minimal requirements for deploying VISYTER was established (table 9). This list was compiled based on the result of the exploration of hardware, explained in chapter 4(4.3). The use of off-the-shelf equipment ensured that the equipment can be installed easily and worked seamlessly without extensive IT support.

Table 9 Installation Requirements of VISYTER

Processor and Memory	At least 2.4 GHz Intel Pentium 4 with 2GB RAM
Software	• Microsoft® Windows® XP Professional with Service Pack 2 (SP2) • Microsoft .NET Framework 3.5 • Microsoft DirectX 9.0b or later • Microsoft Windows Media Player 11 • Latest driver for web camera

Network	High-speed internet connection with at least 2Mbps downstream and 784kbps upstream
Hard Disk Space	10 MB of available hard disk space for installation
Video Camera	▪ A USB video camera: Logitech Orbit AF
Audio	
For Individual Conferencing	An audio headset and microphone, such as a Gigabyte noise/echo cancelling headset
For Group Conferencing	USB speakerphone, or similar unit with audio speakers and an echo-canceling microphone, such as the Phoenix DUET

In addition, several configurations were explored to create a matrix of optimal system configuration based on the available bandwidth and the network configuration of remote clinics (Table 10). For example, sites that utilized DSL connection (medium bandwidth) with a wireless network were limited to utilizing a medium resolution (240x176 dpi) with highest compression (200 bps, keyframe every 5 second) for their conferencing sessions. On the other hand, sites with T1 connections (high bandwidth) with a wired network were able to use the maximum resolution (640x480 dpi) with low compression (1000 bps, keyframe every 1 second), which provided the highest quality video and audio stream for their conferencing sessions.

Table 10 Optimal System Configuration Matrix

	Wireless	Wired
Medium bandwidth (less than 1Mbps upstream)	240x176 dpi 200 bit compression 5 second keyframes	320x240 dpi 500 bit compression 3 second keyframes
High bandwidth (more than 1Mbps upstream)	640x480 dpi 500 bit compression 3 second keyframes	960x720 dpi 1000 bit compression 2 second keyframes

5.4 SUMMARY

This chapter described the conceptual flow of RWP, and how to the PITT model was incorporated into the design and development of VISYTER. VISYTER supported two collaboration types: remote-synchronous and remote-asynchronous. An online portal was developed to support asynchronous collaboration. VISYTER integrated both the online portal and interactive videoconferencing collaboration. All activities were secured using a user management system based on an open-source LDAP technology.

Two types of online portal were deployed for RWP: clinician portal and client portals. The clinician portal provided personalized workspace for RWP's multidisciplinary team members. The portal was equipped with productivity tools, including online calendar, links to client folders, personal documents storage, and links to online rehabilitation resources. The client portal served as information integrator that facilitates the interaction between the RWP's multidisciplinary team members, clients, and caregivers. The portal was equipped with features to support remote-asynchronous collaboration, such as progress tracker, issues tracker, online discussion forum, and electronic forms.

VISYTER was equipped with synchronous collaboration tools, including text chat, multimedia streaming, whiteboard, and power point presentation. VISYTER also had other capabilities, including remote camera control and integration with online portal. This system also had the capability to archive any videoconferencing sessions for later viewing.

The next step was to ensure that the system developed matched what has been identified and designed. In chapter 6, the study to validate the system is described. The result of this study provided recommendations on how the developer improved the usability of VISYTER for RWP.

6.0 VALIDATION OF AN INTEGRATED REMOTE WHEELCHAIR PRESCRIPTION

6.1 VALIDATION VISYTER FOR REMOTE WHEELCHAIR PRESCRIPTION

The adoption of Telerehabilitation (TR) in traditional rehabilitation service depends on whether the service's goals can be accomplished through TR. To support the remote wheelchair prescription project (RWP), a set of requirements has been identified in chapter 4. This set of requirements has been used extensively in the process of design and development to build an integrated system to support TR, called VISYTER (as described in chapter 5). Thus, the next step in the process was to ensure that RWP's goals can actually be accomplished through the use of VISYTER. This step is also known as the system validation phase (Holle & Zahlmann, 1999).

A participatory design was used to validate VISYTER for RWP. In participatory design, users were actively involved in the design and development process to ensure that the product met their needs. However, without sufficient considerations on how the design will be used in workplace, the design may exploit user opinions to create a solution for an incorrect workflow. In addition, traditional participatory design has challenges, including long prototyping cycles and conflicting user inputs. Weng et al. (2007) proposed a method to help mitigate the problems with participatory design by conducting daily observations of the workplace environment (simple ethnography) and formative usability assessment in addition to the simple user-centered design. The combination of these methods allowed the validation process through the evaluation of all possible challenges and solutions while still focusing on the problem at hand.

Following the suggestion presented by Weng, the validation for VISYTER was divided into three phases. The first phase started right after the identification of RWP's requirements. This phase utilized a simplified ethnography method to validate the fulfillment of technical requirements. The second phase started after the development of the prototype. In this phase, two collaborating rural sites were invited to pilot the use of VISYTER for RWP. These pilot sites helped identify the hurdles of deploying and using the system in a real-world setting. The pilot results were essential to creating guidelines and recommendations on how to deploy the system effectively. The third phase started after the completion of all development phases. In this phase, a formative usability assessment was conducted to validate VISYTER. The formative usability assessment was used to identify usability problems and potential usability refinements based on an experiment in a controlled setting. The results from the formative usability assessment study were used to create recommendations to make VISYTER more efficient, effective, and easier to use.

6.2 FIRST PHASE: SIMPLIFIED ETHNOGRAPHY

The use of ethnography has been known to increase the receptivity of system design to the workflow of a particular service (Hughes et al., 1994). However, conducting full ethnographic assessment requires lengthy process. Hughes et al. (1994) discussed a simplified ethnography, utilizing tool analysis and semi-structured interviews, instead of lengthy observations of the workplace. This approach allowed any researcher to view potential usability problems in timely manner by focusing on selected aspects of the workflow and provide relevant work details to designers in a shorter time (Crabtree, 2003).

6.2.1 Methodology

In RWP, simplified ethnography was used to evaluate activities and documents. Simplified ethnography was also used to ensure that VISYTER can support the activities in wheelchair prescription service. Tool analysis was utilized to identify all types of information and documents used in a wheelchair prescription service. The semi-structured interview was used to ensure that the information and documents were included in the design of VISYTER.

The tool analysis explored and evaluated the following documents:

- Client Intake Form and Letter of Medical Necessity Template
- Functional Everyday with Wheelchair (FEW) Pre and Post Service Form and FEW-Capacity Form
- Demographic Pre and Post Service Forms

Subsequent to tool analysis, two clinicians from the Center for Assistive Technology at the University of Pittsburgh Medical Center (CAT-UPMC) participated in the semi-structured interview. These clinicians are very familiar with the workflow of wheelchair prescription service. Interview sessions were conducted to validate that VISYTER supports information needs of all actors in RWP. For example, the tool analysis had validated the need for access to client's health status in the Client Intake Form during the initial data collection phase. During the interview, clinicians evaluated an online portal prototype containing the Client Intake Form and gave feedback as to whether the prototype meets the information requirements for data collection phase. If the clinician considered the prototype to be sufficient, then the use of the technology in the design was considered valid. This approach ensured that the design was valid prior to spending a significant effort and resources in developing the system itself.

6.2.2 Results

Table 11 presented the result of the tool analysis. This table lists the data items of various types (including video) identified from documents and activities of wheelchair prescription service. These data items were required to complete the wheelchair prescription service. The list was evaluated by clinicians to ensure that all necessary information was included.

Table 11 Data Items Required for Wheelchair Prescription

Data Items from Documents	Data Items from Activities
Client Intake Form Health status data (over time) Functional assessment data Environment Assessment data Device (wheelchair) specifications	*Consultation/Assessment* Video and audio streams of remote site Assessment video Environment video
Demographic Form Demographic data Current wheelchair data Preferences	
Functional Everyday with Wheelchair (FEW) Form Client satisfaction data	

This data item list was validated to the list of technologies included in the design of VISYTER using the semi-structured interview. The result of this process is a matrix of IT components and information requirements, which was presented previously in table 7.

6.2.3 Summary

The result of the identification phase was validated using a simple ethnography approach consisting of tool analysis and semi-structured interviews. The result of this process was a validated list of data items required to successfully complete the tasks. This list was used to populate the matrix of requirements, IT components, and data types. In RWP, the list mapped selected technologies (videoconferencing, content management system, and database) and workflow phase (initial data collection, data documentation, finalizing documentation, and device fitting/delivery). The complete matrix is available in Section 4.4, table 45. Using this approach, the selected technologies were validated with the initial requirements to ensure that all necessary data can be accessed through VISYTER.

6.3 SECOND PHASE: PILOT TESTING IN RURAL CLINICS

After the completion of VISYTER prototype, two rural clinics were invited to pilot test VISYTER in actual RWP assessment between the clinics and CAT-UPMC. In this test, VISYTER was used to support a client assessment session through teleconsultation. During this session, VISYTER connected an expert clinician to a multidisciplinary team at the rural clinics, which consisted of a generalist clinician and an RTS. The expert clinician collaborated with the multidisciplinary team in real-time throughout the assessment session. During the session, the expert clinician provided the following to the generalist clinician: advice on seating system frames, bases, and accessories; knowledge of policy implications and funding mechanisms; and education on how physical impairments and medical necessities related to decisions about wheeled mobility and seating options.

A preparatory session was conducted with all generalist clinicians from the rural area clinics prior to conducting any actual assessment session. This session was used to introduce the functionalities of VISYTER to the clinicians, and also to test VISYTER's session archiving features. Most clinicians found VISYTER's point-and click user interface to be relatively intuitive, which allowed them to understand the system without special training session. In addition, prior to any teleconsultation with real clients, both generalist and expert clinicians reviewed RWP workflow and protocols by going over a checklist to ensure a smooth teleconsultation session. This review session prepared clinicians with potential problems, such as spike in network connectivity, or a dropped call.

Deploying VISYTER at these rural clinics required minimal involvement of the clinic's information technology (IT) support. The most common task that involved IT support was to ensure that the settings of the network in the Rehabilitation Engineering Research Center for Telerehabilitation (RERCTR) and both rural clinics allowed the establishment of a direct connection between the expert clinician and the multidisciplinary team at the rural clinic for a teleconsultation session. This task was accomplished by reviewing and modifying the network settings on both sides of the communication, ranging from opening ports in the firewall, creating forwarding protocol to allow both ends of the communication line to recognize each other, to filtering packages to allow only connection from known sources.

6.3.1 Methodology

Two rural area clinics joined the VISYTER's pilot test: DuBois Regional Medical Center (DRMC) and Charles Cole Memorial Hospital (CCMH). These two sites were connected to the RERCTR during the teleconsultation session. Four generalist clinicians (two generalist clinicians from each rural area clinic) and one CAT-UPMC's expert clinician ran teleconsultation sessions to conduct RWP through VISYTER. The frequency of the teleconsultation typically was two to three times a month per site.

Dubois Regional Medical Center, Dubois, Pennsylvania

The first rural area clinic that joined the pilot testing was DRMC, located in rural Dubois, PA, about 125 miles apart from CAT-UPMC in Pittsburgh, PA. A web camera (Logitech Orbit MX) was sent and installed on a desktop computer in the wheelchair assessment clinic at DRMC. The hospital network was connected to the Internet by a DSL line with a downstream bandwidth of 5 Mbps and an upstream bandwidth of 1 Mbps, however the desktop computer at the clinic was connected to the hospital's network through a wireless connection.

The deployment process of VISYTER at DRMC's desktop computer was without problem. However, the initial videoconferencing test run failed due to network and firewall issues. The wireless connection at DRMC was heavily congested in day time, due to the heavy use of the hospital's information management system. Therefore, the wireless network at DRMC was deemed too slow to be used for a real-time videoconferencing. This problem was solved by connecting the desktop computer directly to an existing DSL line, with downstream bandwidth of 1.5 Mbps and upstream bandwidth of 728 kbps.

After several teleconsultation sessions, an interview was conducted to obtain feedbacks from the multidisciplinary team at DRMC. Both generalist clinicians and RTS felt that they were able to have a good flow on the assessment session. The generalist clinicians also mentioned that their client did not feel that the expert was communicating from another place, as if VISYTER was truly transparent to them. The team also mentioned about some problems with the DSL connection, which dropped several times during the teleconsultation session. The team was able to fix this problem by manually reconnecting the line. However, all clinicians involved in the teleconsultation session agreed that the connection problem did not hinder the assessment session.

Charles Cole Memorial Hospital, Coudersport, Pennsylvania

The second clinic that joined the pilot testing was CCMH, located in Coudersport, PA, about 300 miles away from the CAT-UPMC. Similar to the first pilot site, a web camera (Logitech Orbit MX) was sent and installed on a notebook within the wheelchair assessment clinic. CCMH was connected to the Internet by a T1 connection (upstream and downstream bandwidth of 1.5 Mbps), however the wheelchair clinic's notebook was connected to CCMH's network via a wireless connection.

The wireless network setup at CCMH was not stable. This setup was not ideal for VISYTER as videoconferencing session required a reliable and stable network to stream all video and audio packets to every videoconferencing participants. To overcome this challenge, VISYTER’s audio and video compression was maximized to produce smaller packets of data. This setup allowed VISYTER to stream the data more frequently. In addition, many unnecessary applications on the notebook were shut down to improve the performance of the notebook’s processor.

The combination of the use of a notebook and wireless network introduced on average 1 second delay between responses during a teleconsultation session. However, even with the lag, the multidisciplinary team at CCMH agreed that they were also able to have a good workflow on the assessment session. The main T1 connection from CCMH's main hospital was more stable than DRMC's DSL connection as no connection drop was encountered anytime during CCMH's teleconsultation session.

6.3.2 Results of Pilot Test

All participants that joined the pilot testing agreed that they were able to collaborate in real-time with minimal disruption, both in audio and video. Both multidisciplinary teams at rural clinics felt that the flow of the service was smooth although an abundant amount of information was relayed back and forth between sites during each teleconsultation session.

Based on an interview conducted after several teleconsultation sessions, the findings from the pilot studies can be summarized as follows:

- VISYTER allowed the teleconsultation session to have the same quality of evaluation with a face-to-face assessment
- VISYTER's performance depended heavily on the quality of the computer and network
- VISYTER will potentially face the same issues with firewall setting in any healthcare institution

Same Quality of Evaluation with Face-to-Face Assessment

The expert clinician agreed that VISYTER met the needs of TR by delivering ideal video and audio quality for the videoconferencing session. In addition, the expert clinician stated that the same quality of evaluation would be given if the client was able to travel to CAT-UPMC. This level of evaluation was made possible because VISYTER allowed the expert clinician to monitor the therapy session in real time, ask necessary questions, and receive responses in a timely manner. The expert clinician also mentioned that talking in a slow clear voice increased the clarity of any verbal communication conducted during the session.

The online portal was not used as extensively as the videoconferencing system mainly because both rural area clinics already had their own electronic health record system. For privacy reason, the record could not be shown through VISYTER. However, the online portal was still used as an important resource for the clinicians, for example, to store and retrieve documents/form templates required in the assessment process.

Wired is better than wireless, desktop computer is better than laptop computer (notebook)

The use of regular Internet network (due to the limited access to Internet2 from rural clinics) reduced the maximum quality of the videoconferencing due to two reasons: bandwidth limitation and unstable network condition. Compared to Internet2, the bandwidth available in regular Internet was relatively small. Additionally, the improvement in network control in Internet2 increased the speed and stability of the network. The use of wireless network to connect to the regular Internet network reduced the speed and stability of the network even further. The wireless network's performance is determined by the number of users sharing the network. If a large number of users access the network at the same time, the speed may drop significantly. These limitations did not exist in a wired connection. A wired connection had more control on how the audio and video streams within the network are transferred, and redirection through a wired network allowed the data to be streamed properly, even in heavy network traffic.

The compression algorithm in VISYTER required a certain level of computing power. In a laptop computer, the processing power may fluctuate with the processor's temperature. When the processor was overheated, a laptop would automatically reduce the processing speed, which may interrupt video and audio compression process during a real-time videoconferencing session. On the other hand, a desktop computer had larger fans that reduce the chance of overheating. Thus, conducting real-time videoconferencing on a desktop computer produced better, more stable videoconferencing experience when compared to a laptop computer.

Firewall/Network Issues

VISYTER required real Internet address for every participant in a videoconferencing session. Any participants residing behind a firewall required a specific setting to be included within the firewall's rules, which generally required the opening or forwarding of several ports. Once the recommended ports were properly managed, VISYTER was able to connect the multidisciplinary team from both rural clinics and the expert clinician.

In general, most healthcare institutions had strict firewall requirements to protect the security of their network from intrusion. Therefore, the firewall and network issues that VISYTER faced are universal. Any healthcare institution's network would potentially require a modification or acceptance to allow any type of videoconferencing equipment to be added into the network.

Table 12 Comparison of Network Requirements: VISYTER and Common Videoconferencing System

VISYTER	Common Videoconferencing System
In network with multicast	H.323 Ports (IP based video conferencing):
Port 5004, UDP	* 80 - Static TCP - HTTP Interface (optional)
Port 5005, UDP	* 389 - Static TCP - ILS Registration (LDAP)
Port 8000, HTTP	* 1503 - Static TCP - T.120
	* 1718 - Static UDP - Gatekeeper discovery (bidirectional)
In regular network	* 1719 - Static UDP - Gatekeeper RAS (bidirectional)
Port 7004, UDP	* 1720 - Static TCP - H.323 call setup (bidirectional)
Port 7005, UDP	* 1731 - Static TCP - Audio Call Control (bidirectional)
Port 8000, HTTP	* 8080 - Static TCP - HTTP Server Push (optional)
For secure login	* 1024-65535 Dynamic TCP H245
Port 443, HTTPS	* 1024-65535 Dynamic UDP - RTP (Video data)
	* 1024-65535 Dynamic UDP - RTP (Audio data)
	* 1024-65535 Dynamic UDP RTCP (Control Information)

Table 12 compares the network modification requirements for VISYTER with the requirements from common third-party videoconferencing systems. This comparison shows that VISYTER's network specifications are more lenient than common third-party videoconferencing systems. Therefore, maintaining the network to allow any teleconsultation using VISYTER requires less effort from the healthcare institution when compared to common third-party videoconferencing systems. This leniency may potentially make VISYTER more attractive to healthcare institutions that have limited IT support.

6.3.3 Summary of Pilot Testing in Rural Clinics

The pilot testing was performed to inspect and validate VISYTER in real-world setting. In this test, VISYTER was deployed to two rural clinics: DRMC and CCMH. These two clinics used VISYTER to collaborate with an expert clinician located in Pittsburgh, PA. VISYTER was used primarily to provide real-time videoconferencing between the sites. Both sites' multidisciplinary team agreed that they were able to have a good collaboration during a teleconsultation through VISYTER.

The results also displayed that VISYTER was easy to deploy. VISYTER was able to deliver real-time assessment over distance with similar quality to traditional assessment conducted by a face-to-face setting. In addition, VISYTER had minimal network requirements when compared to common third-party videoconferencing systems, allowing VISYTER to be used with minimal involvement and maintenance by the IT support from both rural clinics.

6.4 FORMATIVE USABILITY ASSESSMENT

Usability is the measurement of how useful a system is to help users achieve specific goals (Nielsen, 1993). Four aspects of usability are commonly used to build a framework of usability testing: effectiveness, efficiency, error recovery, and satisfactory level. Effectiveness measures the ability of the system to support users in achieving specific goals. Efficiency refers to the time needed for users to perform tasks to achieve these goals. Error recovery denotes the ability of the system to help users recover from error, guiding them back to the proper path to achieve their goals. Satisfactory level measures the system's ability to satisfy user's expectation.

The use of user-centered design is essential in the refinement of any technology's usability to comply with user's needs. In VISYTER, formative usability assessment was conducted to validate the usability of the system. Formative usability assessment is a study that emphasize on diagnosing the usability of a system by analyzing the user's experience with the system. This type of study typically requires small number of participants to perform in-depth identification of both usability problems and potential usability improvements. The study can usually be conducted in a short period of time to gain quick insight into the usability challenges faced by the users of the system. Feedbacks gathered are usually qualitative in nature, which plays an important role in identifying existing and future usability problems (Ede, 1998; Dumas, 1999). The study corresponds with the technical pilot study for validating a system defined by Holle & Zahlmann (1999).

The formative usability assessment for VISYTER was conducted after the completion of the development phase. The goal of the assessment on VISYTER was to identify usability challenges and ideas that could be refined further to improve the usability of VISYTER in supporting RWP. The result of the study was a set of usability recommendations that was used to improve VISYTER in its next iteration of the system development life-cycle. Several questions to be answered through this formative assessment were as follows:

- Did the system provide the support to conduct RWP according to the requirements?
- Did users find some tasks especially difficult to perform?
- Did some tasks take more efforts than expected to complete?
- Did the features provided within the system help users complete their tasks faster?
- Were parts of the interface error-prone?
- According to the user, what were the strength and the weakness of the system?
- What kind of additional features beyond the original requirements were required to further support the user?

6.4.1 Information Management Activities

In RWP, VISYTER can be considered as a type of information management system because of its unique ability to manage any information flow between its users. For example, during a teleconsultation session between generalist clinicians and expert clinicians, VISYTER was used as a system that manage the transaction of information in real-time. In the process of document exchange between RTS and generalist clinician, VISYTER became the system that managed the transaction of information asynchronously. Four activities are considered essential in information management (Lansdale, 1988): 1) gathering the information from a source outside of the system; 2) adding/storing new information into the system; 3) retrieving the information from the system; and 4) modifying/organizing the information within the system to maintain the information's integrity.

In chapter 4 (4.2.3), four roles have been identified in RWP: physician, generalist clinician, expert clinician, and rehabilitation technology supplier. Observation of the service workflow during the pilot testing (previously discussed in 6.3) from the information management perspective revealed a set of information management activities specific for each role within each phase of RWP's workflow. Table 13 lists all the information management activities in RWP's workflow, grouped by phase and roles. Identifying these activities was vital to recreate a model to capture the dynamic of the service delivery.

Table 13 Information Management Activities in Remote Wheelchair Prescription's Workflow

Phase 1 - Initial Data Collection

Physician*

- Gathering client's information
- Storing client's information

Phase 2 - Data Documentation

Generalist Clinician

- Retrieving previously stored client's information
- Gathering new client's information through assessment
- Modifying client's information based on assessment result
- Storing other new client's information

Expert Clinician

- Retrieving previously stored client's information
- Modifying client's information: Adding expert's comments in addition to clinician's assessment result

Phase 3 - Finalize Documentation

RTS

- Retrieving previously stored client's information
- Modifying client's information based on home assessment result

Generalist Clinician

- Retrieving previously stored client's information
- Modifying client's information: Add comments/modification in addition to supplier's home assessment result

Physician**

- Retrieving previously stored client's information to approve wheelchair recommendation

Phase 4 - System Delivery and Fitting

Generalist Clinician

- Retrieving previously stored client's information
- Gathering new client's information through fitting session
- Modifying client's information based on fitting session result
- Storing other new client's information

Expert Clinician

- Retrieving previously stored client's information
- Modifying client's information: Adding expert's comments in addition to clinician's fitting session result

Notes:

* Physician did not use VISYTER on this phase. All information were generally sent by client's Primary Care Physician office in paper-based forms, and were usually transferred into the system by a clinical coordinator

** Physician's signature was required on the paper-based document. At the present, VISYTER did not have the ability to put in digital signature to the documentation. In addition, most insurance company policies require hard copy of the document. Therefore, VISYTER can only provide the client's complete information to physician.

6.4.2 Methodology

The formative usability assessment utilized three methodologies: 1) think-aloud assessment; 2) post-study questionnaire; 3) and in-depth interview. The assessment was conducted in a controlled lab environment. Participants of the formative usability were potential members of the multidisciplinary team that would use VISYTER to deliver RWP. Each participant was invited based on their roles.

Think-aloud Assessment

In the think-aloud assessment, participants were asked to perform a set of scenarios using VISYTER while verbally describing their intentions and actions to the researcher. With this approach, participant's method of solving a problem using VISYTER can be observed, thus allowing identification of potential usability problems and improvements. All think-aloud sessions were recorded to allow the researcher to go back and review any comments and gain verbatim quotes from the study participants at a later time.

Four scenarios were created based on the information management activities of each role within the RWP delivery. The structures of the scenarios for each role were as follows:

- For physician role:
  - Retrieve and review previously stored client information in Client Intake Form
  - Review wheelchair recommendation in Client Intake Form
- For generalist clinician role:
  - Retrieve previously stored client information in Client Intake Form
  - Review and modify client's information based on the result of the physical/functional assessment session, home assessment, and fitting/delivery session
  - Store additional new information on the client in Functional Everyday with Wheelchair Form (FEW) Pre-Service, FEW Post-Service, Demographic Form Pre-Service, and Demographic Form Post-service.

- For expert clinician role:
    - Retrieve and review previously stored client information in all related documents (Client Intake Form, FEW Pre-Service, FEW Post-Service, Demographic Form Pre-Service, and Demographic Form Post-Service)
    - Modify client information to add comments as necessary
- For Rehabilitation Technology Supplier role:
    - Retrieve and review previously stored client information in Client Intake Form
    - Add new information based on the result from home assessment session

To help the researcher identify potential usability problems and improvements, 12 usability foci was provided:

- During any activities that gathered new information:
    - Did the system helped user to find information that they need from an external source (for example: client)?
    - Did the system allow user to gather information faster?
    - Can user still get the correct information even though an error happens?
    - Did the user feel that the system is easy to use to gather new information?
- During any activities that modified existing information
    - Did the system allow user to modify information?
    - Did the system allow user to modify the information faster?
    - Can user recover from error during the modification process?
    - Did the user feel that the system is easy to use to modify stored information?
- During any activities that retrieved and/or reviewed stored information
    - Did the system allow user to retrieve information about the client (in the form of documents or archives) from within the system (for example: in the database)?
    - Did the system allow user to retrieve the correct information in a timely manner?
    - Can user recover from error during the retrieving process?
    - Did the user feel that the system is easy to use to review and/or retrieve information?

Post-study Questionnaire

The formative usability assessment utilized a post-study questionnaire from the IBM Post-Study System Usability Questionnaire (PSSUQ). This questionnaire consists of 19 close-ended questions on three categories: system usefulness, information quality, and interface quality. The PSSUQ is attached as the Appendix A. In this questionnaire, system usefulness measures the user's belief in the system to support their tasks, information quality measures the user's belief in the system to provide the necessary information to support their tasks, and interface quality measures the user's view on the interface layout. This questionnaire has been found to be both reliable and valid for lab-oriented usability evaluation (Lewis, 1995).

In-depth Interview

The in-depth interview was used to elicit more elaborate explanation on any potential usability problems or improvements. The questions used during the in-depth interview were loosely based on the Strength-Weakness-Opportunity-Threat (SWOT) approach. For example, a usability problem would fall into the 'weakness' of the system. The researcher would investigate this problem by asking how severe the problem was and if the problem happened in real-world setting. Based on the result, a researcher would rate the usability problem and sort the problem based on the degree of severity. Another example, an approval or an exclamation on how easy or good a particular component of the system would be classified into the 'strength' of the system. Potential improvement of the usability would fall into the 'opportunity' of the system while potential or future usability problems would be categorized as 'threat'. The questions used for the in-depth interview is attached as the Appendix B.

Study Participants

The formative usability assessment involved individuals currently delivering wheelchair prescription services in face-to-face setting to assess VISYTER's compliance with their daily needs and challenges. All four service provider roles were invited to participate in the formative usability assessment: generalist clinician, expert clinician, RTS, and physician.

Generalist clinicians were recruited from the University of Pittsburgh's School of Health and Rehabilitation Sciences and rural clinics. These clinicians had an interest in delivering seating and mobility service, as well as in TR. Prior to joining RWP, these clinicians observed the process of delivering seating and mobility service in the CAT-UPMC to develop further knowledge in this specialty area. They were trained on documentation procedures for the provision of wheeled mobility and seating interventions. These clinicians have also been trained on how to administer and score the progress of the therapy using measurement tools.

Expert clinicians, RTS, and physicians for the formative usability assessment were recruited from CAT-UPMC. These individuals have been involved with the wheelchair prescription service for many years and were very familiar with the wheelchair prescription process.

6.4.3 Protocols

As previously mentioned, each formative usability assessment was divided in three segments, starting with the think-aloud assessment, followed by post-study questionnaire. The result of the think-aloud assessment and the post-study questionnaire were used in the in-depth interview segment, allowing a deeper investigation to clarify any potential usability problems or improvements identified during the previous segments of the study. The total time for the three segments averaged in 30-45 minutes to complete.

First Segment: The Think-aloud Assessment

The think-aloud assessment started with user training, both on the system usage and the think-aloud protocol itself. Most individuals did not practice ‘thinking aloud’ in their daily activities; therefore the concept need to first be introduced and trained by each participants prior to the assessment itself. During the assessment, participants were reminded to verbally express any thoughts or any strategies they used to complete a specific task. The screen was recorded through the use of screen capture software. A log that recorded any comments made by participants was kept during the assessment.

The participant's role in the delivery of wheelchair prescription service determined the scenario presented and the section of VISYTER to assess. For example, clinicians were asked to evaluate both the remote-synchronous and the remote-asynchronous collaboration components of the system, while the RTS and physicians were required only to evaluate the remote-asynchronous collaboration component. The scenarios were informed orally to the participant, one task at a time. For every task, participants were asked to identify potential usability problems through the use of three questions:

- Can participant form a strategy to complete the task?
- Did the system hinder the participant from following said strategy?
- Did the system provide result according to participant's intention?

Second Segment: The Post-Study Questionnaire

In the second segment of the assessment, the IBM PSSUQ was administered to the participant. Each participant filled out the questionnaire and provided written comments on some aspect of the system described through the questionnaire. The questionnaire consisted of 19 questions and took about 5-10 minutes on average to complete.

Third Segment: The In-Depth Interview

Afterward, the study proceeded into the third segment, an in-depth interview based on the result of the first and second segments. As previously mentioned, the in-depth interview was based loosely on the SWOT analysis approach. The result of the in-depth interview was a list of usability topics, grouped by service roles, and sorted by degree of severity.

6.4.4 Result Analysis

Five generalist clinicians were recruited to conduct the formative usability assessment. All generalist clinicians were able to provide feedback through the questionnaire and in-depth interview; however, only two were able to complete the think-aloud assessment section. Two expert clinicians and RTS were also recruited. Only one physician was able to participate in the formative usability assessment due to the physician's availability and time constraint.

The resulting feedback from the formative usability assessment were summarized and sorted by its degree of severity. For example, a simple change of color in the interface would be categorized as a cosmetic interface problem with very low severity, while an error in the system that prohibited a task to be completed was considered a very severe usability problem.

Overall Summary of Result

- Study participants agreed that the system provided the support to conduct RWP according to the initial requirements
- Participants expressed that they were able to perform their task easily and seamlessly (with minimal efforts) due to the intuitive user interface
- Participants suggested some modification to the user interface to reduce potential confusion caused by broken paths

Strength of VISYTER

- Generalist clinicians expressed that the system was able to support them by allowing expert clinicians to join an assessment session seamlessly. They mentioned that the presence of a peer or an expert specialized in this particular field (seating and wheeled mobility) boosted their confidence in delivering the service. Additionally, generalist clinicians pointed out that the teleconsultation provided a great learning platform, by having someone to provide on-the-spot mentoring and pointing out missing assessment fields during the session. Generalist clinicians also agreed that the online portal allowed the team to create a more comprehensive, complete wheelchair recommendation for the client.
- Expert clinicians agreed that the system provided support for all their needs to deliver a remote assessment for wheelchair prescription. Expert clinicians were also willing to continue their support in the next iteration of the software development life-cycle, if necessary.
- RTS pointed out that the remote-asynchronous collaboration component of VISYTER (the online portal) can effectively disseminate important information about the client prior to face-to-face meeting. With this information, RTS can prepare several strategies or demo equipment that can be presented during the initial meeting with the client, instead of having to return to the clinic or the clients’ home again at later time.

- RTS also revealed that the use of the online portal could improve the efficiency of the remote collaboration effort by allowing information to be available anytime anywhere to all team members. They agreed that the availability of the information online would eliminate the delay in creating the required documentation. For example, RTS can provide information directly in the electronic format without having to send the document through regular post mail. Also, the information about a client would not be confined within the mailbox of the person while the person was out of office. In this setting, another team member could act upon the information to allow the process to continue immediately. The physician, generalist clinicians, and expert clinicians also agreed on the possibility of VISYTER to streamline the process by reducing the delay in waiting.
- RTS also mentioned that VISYTER provided a centralized document management system, which allow them to gather all required information about the client from a single site. With this approach, RTS felt that they would be able to reduce up to 2 hours of information gathering per client through the use of this system.
- Both generalist clinician and RTS agreed that the standardized electronic forms helped focus the assessment on the most important aspect to assess the client. The standardized electronic forms helped them to create recommendations with less variability and less errors.

Weakness of VISYTER

- During the walkthrough of the system, both generalist and expert clinicians found some broken paths to access the document. The broken paths can be encountered if the clinician decided to click on the detailed phase of the workflow. Clinicians expected that a link to the document would be available within the detail of the phase. Although alternative methods to access the documents were available, clinicians mentioned that having a link would help them access the document in a more intuitive manner. Rating of severity: Medium.
- Generalist clinicians mentioned that entering any client's information while assessing the client at the same time was very distracting. Generalist clinicians felt that the important aspect of the assessment should be a smooth interaction between the clinician and client. Having generalist clinician to enter the data by typing in the information distanced them from the client due to the need of going back and forth between the electronic form and the client. Rating of severity: Medium.

- The physician mentioned that the order of information presented in VISYTER's electronic forms were different when compared to the forms that they encountered daily. The physician would rather have summarized information in the form of Letter of Medical Necessity first, before the complete detail of the client in the Client Intake Form. With this approach, a physician can build a mental image of the client prior to reading the detail of the client. The summary would also make the process easier and faster for the physician's assessment. Rating of severity: Low.

Opportunities for VISYTER

- To overcome being distracted from their clients during the assessment session, generalist clinicians mentioned about other possible data entry methods. Currently, some clinicians utilized voice-to-text software, such as the Dragon Naturally Speaking, to enter dictation into electronic forms. The clinicians suggested that similar approach might be appropriate to entering data in VISYTER as well.
- Generalist clinicians also inquired about the possibility of having two types of communication channel: one being public (can be heard by the client), and the other one being private (communication only between the clinicians).
- To overcome the unstable remote synchronous collaboration sessions (teleconsultation sessions), the expert clinicians inquired about the possibility of creating an automatic bandwidth adjustment module. The module should automatically adjust the audio and video stream to the available bandwidth, for example, decreasing the video quality gracefully when the network became unstable, or dropping the video altogether while maintaining the audio channel, and increasing the quality once the network became stable.
- RTS inquired if VISYTER could also interface with their companies' systems to provide a smooth information flow between the many entities included within the wheelchair prescription service.

Threats to VISYTER

- Clinicians, both experts and generalists, mentioned that the system was easy to understand. However, they would still require some time to 'get used to' the system. Clinicians also mentioned that some system behavior was not intuitive enough. For example, the 'save document' button was placed on top of the document and at the bottom of the document, requiring clinician to scroll all the way up or down to access them. Although these conditions did not hinder clinicians from completing their tasks, these conditions might become a problem during the ‘peak hour’, when clinicians were required to complete their tasks as fast as possible. Clinicians suggested that additional one or two training sessions be given to a new user to assist with any usability problems.

- The requirement of a stable, high-bandwidth internet for providing the remote-synchronous collaboration support was deemed to be too strict by the expert clinicians. The expert clinicians mentioned that during the pilot study, they encountered several unstable or shaky teleconsultation sessions, with some dropped lines, due to the unreliable Internet network. However, the expert clinicians agreed that the problem was not in the VISYTER itself, but in the network that the VISYTER was working with.
- The physician pointed out that the electronic forms used by VISYTER were already available within their hospital’s electronic health record. Rather than duplicating the information, it was suggested that both systems should either be integrated, referring to the same source of information, or have an auto-synchronization capability. However, it was agreed that the separation of the system would provide team members from outside of the hospital system (such as the RTS) a limited access to the client information, which traditionally would be blocked altogether due to the strict privacy and security settings of the hospital. With this in mind, it was inquired that the remote-asynchronous collaboration component (the online portal) of VISYTER to comply with standardized data protection regulations, such as the Health Insurance Portability and Accountability Act (HIPAA).

6.4.5 Summary of Formative Usability Assessment

Usability plays a key role in technology adoption into clinical service (Brennan & Barker, 2008). With the ever increasing demand of healthcare, providers are challenged to provide efficient service. Any introduction of new technology should bring as minimal distraction as possible to the staff providing these services, requiring that the technology fit into the service seamlessly and is intuitive to use.

VISYTER utilized formative usability assessment to gain insight into the usability problems and potential usability improvements. The study was conducted with the assistance of individuals who are currently employed to deliver wheelchair prescription services. The formative usability assessment was divided in three segments: think-aloud assessment, post-study questionnaire, and in-depth interview.

The inputs of the formative evaluation study were:

- Documents currently used in the service, such as: Letter of Medical Necessity, Client Intake Form, and Functioning Everyday with a Wheelchair (FEW) Form
- Type of roles in the workflow
- Usability questionnaire in the form of IBM PSSUQ
- Scenarios, derived from atomic information management actions within TR service workflow

The outputs of the formative evaluation study were:

- Analysis of usability problems and potential improvements found during the think-aloud assessment
- Subjective recommendations on the system's effectiveness, efficiency, and ease of use from the questionnaire and in-depth interview
- Prioritized list of change

Based on the result, VISYTER was considered to be acceptable and usable to support RWP by having an expert clinician via teleconsultation supporting a generalist clinician at a remote site. The team members agreed that VISYTER provided the functionalities was required to properly prescribe a wheelchair remotely.

VISYTER still required several minor modifications, especially in the order of presenting information within the system. The team also mentioned several threats to VISYTER's implementation in real-world setting, including training, bandwidth instability, and security and confidentiality issues. These potential usability problems and improvements were addressed in the next iteration of VISYTER's development cycle.

6.5 SUMMARY

Presented in this chapter are the methodologies and results of the system validation of VISYTER for RWP. The system validation was conducted using a participatory design in three phases: validation phase after requirement identification and verification, validation after prototype development, and validation after the development of VISYTER. The result of the validation phase demonstrated that VISYTER can be used to properly support both teleconsultation and documentation phases of RWP.

The method presented in this chapter is also standardized, thus can be used to validate VISYTER for any other applications of TR beyond RWP. The system validation process was able to identify usability problems, potential usability improvements, and potential threats to VISYTER. These recommendations were used to further refine and improve VISYTER in subsequent development iterations. In the next chapter, the result of the summative usability assessment and also evaluation between VISYTER and high-end, non-integrated systems to deliver TR application will be presented.

7.0 REMOTE WHEELCHAIR PRESCRIPTION: SYSTEM EVALUATION PHASE

7.1 EVALUATION OF SYSTEM: BENEFITS OF INTEGRATED SYSTEM COMPARED TO NON-INTEGRATED SYSTEMS

In previous chapters, the design, development, and refinement process of VISYTER, an integrated system to deliver Telerehabilitation (TR) services, has been discussed, specifically to support teleconsultation in the remote wheelchair prescription project (RWP). The use of TR to deliver teleconsultation is not new. For example, teleconsultation has been used nationwide to provide support for post-traumatic stress disorder (Morland et al., 2010), advice and support in emergency situations (Deakin, Evans, & King, 2010), psychiatry consultation for child (Pakyurek, Yellowlees, & Hilty, 2010), etc. However, most telerehabilitation efforts utilize non-integrated systems to support the delivery of the rehabilitation service. For example, Rabinowitz et al. (2010) mentioned the use of POLYCOM videoconferencing system to deliver a telepsychiatry consultation service.

This chapter presented the result of an evaluation study which compared the usability of the integrated system with non-integrated systems commonly used to deliver TR. Specifically, this study compared the usability of VISYTER to a set of systems which consisted of a television, a personal videoconferencing system from POLYCOM, and a paper-based documentation template. The goal of the study was to investigate and discover any benefits that came from the integration of system.

Participants of this study were clinicians, both Occupational Therapists and Physical Therapists with varying levels of clinical experience. These individuals were asked to conduct a short teleassessment session on both the integrated and the non-integrated systems. The experience of using both systems first hand allowed each individual to give feedback on the system's use. This feedback was afterward analyzed to measure the usability of each system.

7.2 METHODOLOGY

The evaluation study focused on four key areas: 1) can the user perform and eventually finish their task using the system (effectiveness); 2) can the user complete their tasks in a timely manner (efficiency); 3) can the user progress with their tasks even after encountering problems/errors (error recovery); and 4) does the user consider the system to satisfy their expectation (satisfactory). A within-subject study design was used in this study to evaluate the systems used to deliver TR on macro, controlled environment level (Engelbrecht, Rector, & Moser, 1995). This study evaluated the system by comparing the usability of the integrated system to non-integrated systems in a teleassessment session, conducted by the clinicians. The use of within-subject study design allowed the study to include practitioners of varying rehabilitation fields, including occupational therapists and physical therapists. Participants were asked to run teleassessment scenarios in a controlled-condition session. The tasks were created based on the detailed activities within the four phases of TR workflow, which was discussed in chapter 4.

The design of this evaluation study used a very similar approach to several previous studies on system usability (Zeng, 2004; Bunker, 2005; Scotch, Parmanto, & Monaco, 2008). A randomized design were used to assign participants into the counterbalancing sequences: half of the participants started the study with VISYTER and then moved to use POLYCOM, while the other half started with POLYCOM and then move to VISYTER. This crossover design was used to remove carryover effect from the sequence.

The use of a controlled-condition session was shown to be sufficient to identify improvement of the usability aspect of a system in a timely manner (Holle & Zahlmann, 1999). In addition, the use of controlled-condition session allowed researcher to focus on the core requirements of the system (information management), while reducing distraction from other activities in the service that was not related to information management (such as waiting for documents to physically arrive, or waiting for approval from the clinics to perform an assessment). For each system, usability was measured from four aspects: effectiveness, efficiency, error recovery, and participant's subjective perspective of the system's usability.

The research question for this study was:

"Would integrated, PC-based system (VISYTER) be more usable when compared to non-integrated systems consisting of a television, videoconferencing system (POLYCOM), and paper-based documentation in supporting TR?”

The hypothesis for this study was:

"Integrated, PC-based system (VISYTER) is more usable compared to non-integrated systems consisting of a television, videoconferencing system (POLYCOM), and paper-based documentation when used to support TR."

7.2.1 Summary of the Study

The usability evaluation of VISYTER was conducted from October, 2009 to February, 2010. During the usability evaluation, 26 participants were asked to spend 90 minutes with both systems. In summary, during this time, participants:

- Were given the full explanation of the study, study goals, and expectations of the study.
- Signed a consent form
- For each system (VISYTER and POLYCOM):
    - Were trained to use both systems, starting from turning the system on, controlling the system, accessing and modifying information within the system, and turning the system off
    - Performed 4 tasks derived from real-world assistive device assessment process
    - Answered questionnaire about the usability of the system
    - Participated in an in-depth interview about the usability of the system

7.2.2 Inclusion/Exclusion Criteria

Twenty-six participants, having the following profile characteristics (table 14), evaluated both the integrated system (VISYTER) and non-integrated systems (POLYCOM). Individuals approached for participation were clinicians, 18 years of age or older who had prior experience in providing rehabilitation services as either an occupational therapist or physical therapist). Participants were recruited from the School of Health and Rehabilitation Sciences at the University of Pittsburgh and Center of Assistive Technology at the University of Pittsburgh Medical Center.

Table 14 Profile Characteristics of Summative Usability Study Participants

Clinician Type

Occupational Therapist	4
Physical Therapist	22
TOTAL	**26**

Familiarity with Computerized Data Entry

Have not used at all	3
Used in the past	4
Used not regularly	12
Regularly used in practice	7
TOTAL	**26**

Clinical Experience

Less than 5 years	15
More than 5 years	11
TOTAL	**26**

Knowledge of Telerehabilitation

Have not heard at all	21
Somewhat familiar	5
Currently practicing	0
TOTAL	**26**

7.2.3 Study Scenario

During the usability evaluation, participants were asked to complete four scenarios commonly performed during a wheelchair assessment on each system. The tasks were presented in a specific order to simulate the process of assessing client's activities of daily living (ADL). The scenario and tasks were identified from observing the activities within the remote wheelchair prescription project and refined with the assistance by the remote wheelchair prescription project clinicians. Section 7.3 discussed this protocol, consisting of the scenario and tasks in more details. In summary, table 15 details the tasks that each participant did during the study.

Table 15 Study Scenario Tasks

	Task
	Starting the assessment session by turning on the system and establishing communication with the client
	Reviewing the currently available information by confirming the information with the client
	Assessing the client's ADL and entering new information into the system
	Concluding the session by disconnecting the communication system and turning off the system

7.2.4 Data Collection Instruments

As previously noted, the study measured the usability of the system based on four aspects: effectiveness, efficiency, error recovery, and participant's satisfactory level. Effectiveness is generally defined as the capability of the system to allow its user to accomplish the tasks for which the system was intended. Efficiency is the measurement of the amount of effort and time needed by the user to successfully complete tasks. In error recovery, the study measures the ability of the system to help user recover from error caused either by their own mistake (human error) or the system's fault (system error). Participant's satisfactory level is the measurement of how satisfying the system is to meet the user's expectation.

The study collected two types of data: performance and preference. Performance data were collected through performance metrics, which rely on objective measurements of the events during the study. Preference data were collected using preference metrics, which rely on subjective responses of the study participants. By comparing the result of the performance and preference metrics, an analysis of differences between participants' performance during the study with participants' subjective feeling of usability could be produced.

Three performance metrics were used:

- *Task completion rate.* The study used task completion rate to measure the effectiveness of the system. This metric measured the number of tasks that were completed successfully by participants. The 'quality' of the task completion was also rated. A zero ('0') denoted that the task was completed successfully without prompting. A one ('1') denoted that the task was completed with a short prompting to remind the participant. A two ('2') denoted that the task were completed, although with a long explanation from the researcher. A three (‘3’) denoted the occasion where participant decided to give up on the task (i.e. task was not completed).

- *Time to complete task.* The time to complete each task was measured to compare the efficiency of the system. A system is deemed efficient if the system allowed its user to perform their tasks as fast and accurate as possible. The study analyzed the time based on the recording of the study session to reduce the possibility of participants acting differently due to the time measurement. Each task was broken down to atomic actions to allow accurate comparison of the time used to complete them. For task 1 (starting the session), the study measured the time required to completely start up the system and connect to the client. In task 2, the study measured the time required to access the client’s health information and confirm the information already listed. In task 3, the study measured the time required to inquire new information from the client and enter this into the health record. In task 4, the study measured the time required to completely disconnect with the client and turn off the system.
- *Number of Errors and Error Recovery*. Error was defined as an event that has the potential to prevent a participant from completing a task. Subsequently, an error recovery event was the event where participant encountered an error, but was able to overcome the error and complete the task. Each error event was graded by its error recovery, with '1' for any error that can be recovered with no or minimal participant's intervention, '2' for any error that can be recovered by participant with some support or additional information about the system, and '3' for any error that cannot be recovered by participant.

Two preference metrics were used in the study:

- *IBM’s Post Study System Usability Questionnaire*. This study utilized the same tool with the formative usability assessment discussed in chapter 6.
- *In-depth interview*. Participants were asked to further explain their responses given on the IBM PSSUQ. This explanation was summarized to provide a richer insight of the usability of the system from participant’s perspective.

7.2.5 Study Set-up

The study utilized two sets of equipment to simulate the systems: one set of equipment for the integrated system, and one set for the non-integrated systems. Table 16 shows the list of equipment for each set. For deploying the non-integrated systems, the study utilized a combination of POLYCOM room videoconferencing, connected to a personal videoconferencing set in a desk environment. Participants called their client from the personal videoconferencing set, which utilized a 24” TV as its display. Client’s information was printed out in paper-based form. The integrated system set utilized a desktop PC and a laptop PC. Participants called the client from the laptop PC, which was connected to a 24” LCD monitor as its display. Client’s information was stored in a mini electronic health record system which was integrated inside VISYTER.

Table 16 List of Equipment for Integrated System and Non-integrated Systems Study

Non-Integrated Systems (POLYCOM)	Integrated System (VISYTER)
❖ **POLYCOM’s Videoconferencing Solution, consisting of:** ▪ **Video Conferencing Codec** ▪ **Camera** ▪ **Multipoint Conferencing Unit: POLYCOM MGC** ▪ **Recording and Streaming Server: POLYCOM RSS 2000** ▪ **Internet connection** ❖ **POLYCOM personal solution system** ❖ **Client’s information in a Client Intake Documents, printed out** ❖ **24” TV to connect with the POLYCOM personal solution system**	❖ Desktop PC with the specification of: ▪ Intel Pentium IV X.X Ghz ▪ XMB RAM ▪ Webcamera: Logitech C600 ▪ Speakerphone: Phoenix DUET Executive ▪ Internet connection ❖ Laptop PC with the specification of: ▪ Intel Pentium M 2.0 Ghz ▪ 2MB RAM ▪ Webcamera: Logitech Notebook Pro ▪ Speakerphone: Phoenix DUET Executive ▪ Internet connection ❖ Client’s information in an electronic Client Intake Documents ❖ 24” LCD monitor

The study recorded participant’s screen during the study via a mounted Sony handycam recorder. The recording was used to track the time of task completion and to help the researcher identify usability problems encountered during the session. In addition, the recording also helped the researcher to analyze each participant’s error recovery strategy. Afterwards, the study utilized digital voice recorder to record the audio from the discussion during the in-depth interview.

7.3 PROTOCOL

The study utilized a simulated teleassessment session which was created based on observation of a real teleassessment. This approach was suggested by Neale, Carroll, & Rosson (2004) to evaluate computer supported cooperative works. The teleassessment scenario was chosen because this scenario is the most common activity in TR. By identifying and re-creating representatives from an actual teleassessment setting, findings of the study could be generalized to actual contexts of use (Watts & Monk, 1996).

The teleassessment scenario in this study was created to follow the four phases of workflow observed in RWP: initial data collection, data reporting, finalizing documentation, and system delivery. In real-world setting, clinicians have the responsibility to assess the need of the client and prescribe the equipment accordingly while rehabilitation technology suppliers (RTS) are the ones responsible to perform the device delivery. The system to support TR system would be used to verify the initial client data, collect and store data from the assessment in data reporting, and finalize the documentation based on the assessment. To simulate the initial collection of data, researchers prepared a set of client initial data prior to the study. The client initial data was based on a sample case study that is used to train clinicians in the Center of Assistive Technology at the University of Pittsburgh Medical Center. Study participants used this data to conduct the teleassessment, collect and record assessment data, and finalize the documentation necessary to prescribe the assistive technology required by the client. By using a scenario that mimics closely with real-world setting, participants were able to give additional comments on the system's usability based on their own experiences too. These comments provided a deeper insight on the potential impact of using the telerehabilitation system in real practices.

Prior to the start of the session, each participant were trained on the use of the system (how to turn on, establish connection, pull client information, and disconnect/turn off the system). After the completion of each session, participants were required to complete the PSSUQ questionnaire to evaluate the system from the user's perspective. The results of the questionnaire were utilized to perform an in-depth interview with the participant to investigate the usability problems.

Task 1: Start Up Telerehabilitation System and Connect to Remote Site

In the first task, participants were asked to start up the telerehabilitation system and establish the connection to the remote site. With POLYCOM, participant was required to find the switch to turn the system on, and use the device's remote to call the remote site. Most videoconferencing systems, similar to POLYCOM, can be called through the use of a specific number or address similar to a regular telephone system. In this study, both participant's and client's sites were connected through the internet, thus an Internet Protocol (IP) address was used to call the other site. Most sites with a videoconferencing system would usually print out the steps to connect and the IP address to call in a 'cheat sheet' and placed the printed-out steps nearby the videoconferencing system as a reminder.

With VISYTER, participants need to double-click on a VISYTER's icon on the PC's desktop. Afterward, participants were required to authenticate themselves by entering a specific username and password. Once authenticated, VISYTER displayed the user's profile and automatically set up a list of virtual rooms that were available for the participant to enter. To connect with the remote site, participants needed to enter the appropriate virtual room associated with the remote site.

Task 2: Review and Verify Client's Initial Information

In the second task, participants were required to review and verify any initial information about the client. The initial client information consisted of client's name, address, day of birth, insurance, caregiver information, diagnoses, and/or problems with the client's current assistive technology device. Participants were asked to find this information from the database and verify it with the client through the telerehabilitation system. In addition, participants were also asked to modify/correct any mistaken information. This task corresponded with the initial data collection phase of the workflow.

With POLYCOM, client's initial information was printed out beforehand. This situation simulated a real-world setting where information is prepared before an assessment takes place. Any modifications and/or corrections of the information were written next to the erroneous information with some type of marking either by striking out or putting into brackets. With VISYTER, the client's initial information was stored in a simple electronic health record system, readily accessible from VISYTER's interface. Participants were required to access the client's record by going to the client's folder and opening the proper document that stored this information. Any modifications and/or corrections were entered directly into the electronic health record system by typing the information form a keyboard. The system has the ability to track any changes to the document and automatically create modification trails for auditing purposes.

Task 3: Assess Client's Activity of Daily Living and Enter the Result into Health Record

The third task asked participants to perform a short ADL assessment and enter the results into a health record. Participants gathered the necessary information by asking client to answer or demonstrate specific ADLs. For instance asking the client to demonstrate a weight shift or reaching for an object. This task corresponded with data reporting phase and finalizing documentation phase of the TR workflow.

Similar to the second task, the result from the teleassessment was recorded. With POLYCOM, the result was recorded in a paper-based form. With VISYTER, the result was recorded in the electronic health record. In addition, participants were required to save the document properly in the electronic health record.

Task 4: Disconnect from Remote Site and Turn off the Telerehabilitation System

After performing the teleassessment, participants were asked to disconnect the communication channel with the remote site. In POLYCOM, the call was disconnected by pressing the 'hang-up' button from the remote control. In VISYTER, participants needed to leave the virtual room by clicking the 'exit from conference' button.

Turning off the system was the complete reverse of detailed in the first task. With POLYCOM, participants needed to find the switch to turn the system off. With VISYTER, participants needed to close the application, either by the 'x' button at the top hand corner, or by going into the menu and choosing the option 'Exit'.

Survey and In-depth Interview

At the end of each session, researchers asked participants to complete the IBM PSSUQ. For each questionnaire item, the researcher asked an additional question to gain more insight on the reasoning behind the score.

7.4 RESULTS

Due to the use of mixed methodology in this study (both quantitative and qualitative methods), analyzing the results should be driven by the research problem, rather than by methods (Tashakkori & Teddlie, 1998). Therefore, different methods were utilized to analyze each metrics (performance and preference), and afterwards, the results were reconstructed from the distributed findings.

The study proposed five degrees of possible answers to the question of whether the integrated system (VISYTER) was more usable when compared to the non-integrated systems (POLYCOM): completely more usable, partially more usable, equal in usability, partially less usable, and completely less usable. Completely more usable was defined as the state where all aspects of the integrated system were found to be more usable compared to the non-integrated systems. Completely less usable was defined as the state where all aspects of the integrated system were found to be less usable compared to the non-integrated systems. Partial usability levels were defined as the state where not all usability aspect from one system dominated the other.

7.4.1 Performance Metrics

Task Completion Success Rate (Effectiveness)

The effectiveness of the system was measured through the number of successful task completions, with the task success rate defined as the number of task completions without assistance divided by the number of participants completing the task. The number of task completions was extracted from the recording of the study session by the researcher after the study was completed. This approach blinded participants to the task completion measurement process.

Performance data gained as the result of this approach was quantitative in nature. Any tasks performed by participants that required assistance from the researcher were marked with degree of interventions, ranging from 1 to 3, with 1 = marked tasks that required little assistance, such as short prompting to remind the location of buttons, 2 = marked tasks that required longer assistance, such as reiterating the explanation on how the system worked, and 3 = marked any tasks that was not completed (complete task failure). The result of this approach is detailed in table 17. On average, the task completion success rate did not differs between the two approaches, although VISYTER were considered by participants to be more complex compared to POLYCOM.

Table 17 Task Completion Success Rate

		Successful Completion	Completion with little assistance (intervention=1)	Completion with longer assistance (intervention=2)	Non-completion (intervention=3)
Task 1					
	VISYTER	86%	10%	4%	0%
	POLYCOM	77%	19%	4%	0%
Task 2					
	VISYTER	81%	15%	4%	0%
	POLYCOM	100%	0%	0%	0%
Task 3					
	VISYTER	89%	11%	0%	0%
	POLYCOM	100%	0%	0%	0%
Task 4					
	VISYTER	96%	4%	0%	0%
	POLYCOM	81%	19%	0%	0%
AVERAGE					
	VISYTER	88%	10%	2%	0%
	POLYCOM	89.5%	9.5%	1%	0%

<u>Task 1: VISYTER</u>

Twenty-two out of twenty-six (86%) participants were able to complete the first task (starting up the system and connecting to the client) on VISYTER without assistance. Three participants were able to finish the first task on VISYTER with little assistance, while one participant required longer explanation on how to perform the first task. The main cause of participants' prompting for assistance was the visibility of the available virtual room list. In VISYTER, the available virtual room list was placed inside an auto-hide tab at the left side of the screen. User would need to hover over a small tab labeled 'Venue' to trigger the pop-out of the list. These participants were not able to remember this exact step, and asked for assistance to help them find the list. One of the participant said, "*I am sure that I need to click on an icon to connect, but I could not find it. Where is it?*"

Task 1: POLYCOM

Twenty out of twenty-six (77%) participants were able to complete the first task without assistance. Five participants were able to finish the task with little assistance, while one participant required longer explanation on how to perform the first task. The primary reason for participants' request for assistance was the difficulty to connect to client's system. By default, POLYCOM system required participant to enter cryptic IP address into the system. Although participants could view the list of available remote sites by choosing 'Address Book' from the interface menu, most participants decided to manually enter the IP address. The IP number consisted of numbers and dots (for example, "192.168.0.1"). Several of the six participants requested assistance to troubleshoot an error caused by missing dots (participant entered "19216801" instead of "192.168.0.1"). In addition, to produce a 'dot', participants were required to push the 'right-arrow' button. Several participants required a prompt to remind them on how to produce the dot.

Task 2:

All participants were able to complete the second task (verifying client information) on POLYCOM without prompting (100%). All client information for POLYCOM was printed out and readily available in paper-based format. The integration with electronic health record in VISYTER increased the complexity of the system, which required participants to follow three steps to access their client's information. First, participants were required to select/click on their client's name. Once the system loaded the client's folder, participants need to click on the 'Client Intake Form' link on the left side of the folder. A vertical scrollbar on the right side of the form would then be used to allow navigation through the form. On VISYTER, twenty-one participants

81% were able to complete the second task without prompting. Five participants required short prompting and one required long explanation of the system on how to access the client information. Most of these participants required prompting at the second step (to find the link to the ‘Client Intake Form’). The vertical scrollbar also caused problem for some participant. In VISYTER, the size of the client information display can be resized to fit into user’s screen size. In some cases, participants’ preference of display size obscured the vertical scrollbar (the vertical scrollbar was hidden due to limited display size). In these cases, participants need to find first the vertical scrollbar by either resizing the display or using the horizontal scrollbar to uncover the vertical scrollbar.

<u>Task 3:</u>

Similar to the second task, all participants were able to complete the third task (assessing client and recording assessment result) on POLYCOM without prompting (100%). On VISYTER, twenty-three participants were able to complete the assessment without prompting (89%). For the third task, participants were required to enter the information into the electronic health information system and save the document afterwards. Three participants (11%) were not able to recall the location of the ‘Save’ button, thus required prompting to find it.

<u>Task 4:</u>

At the fourth task (disconnecting from client and turning off the system), only one participant required prompting to perform the task on VISYTER (4%). This participant forgot to turn off the system after disconnecting from the client. After being prompted to do so (“*You need to also turn off the system*”), the participant was able to turn off the system without being guided. On POLYCOM, five participants (19%) required prompting to disconnect from their client. The POLYCOM system required the user to press the disconnect button twice to end a call (to prevent from accidental disconnection). These participants were not able to realize that they have not been disconnected. After being prompted, all participants were able to disconnect from the client without being guided.

<u>*Time on Task (Efficiency)*</u>

The efficiency of the system was measured by analyzing the time that each participant needed to perform a task (time on task). The time on task data was also extracted from the recording of the study session, similar to the previous analysis. Observations in the clinic showed that each clinician had different ways to conduct their assessment. For example, an assistive device assessment commonly follows a standardized Client Intake form. However, clinicians at times put more emphasis on certain parts of the assessment by adding questions beyond what was written inside the standardized form. To standardize the measurement for tasks that involved an interaction with the client (i.e. task 2 and 3), the study extracted time to perform three sub-tasks with different amount of interactivity. For example, in task 2, the study extracted the time to perform verification of client's identification (such as SSN or first name/last name) as an example of a sub-task that required minimal interactivity between the participant and the client. Another example, in task 3, the study extracted the time to perform identification of client's capability of performing weight shift as an example of a sub-task that required a lot of interaction between the participant and the client. This task required the client to answer some questions from the participant.

For task 2, verification of client information, the study extracted the time to perform the following: verification of client's social security number (a sub-task that required minimal interaction between participant and client), verification of client's home address (a sub-task that required some interaction between participant and client), and verification of client's problem with current assistive device(a sub-task that required a lot of interaction, questions and answers back and forth between participant and client). Similarly, for task 3, client assessment and data entry the study extracted the time to perform the following: assessment of client's capability of managing finance (a sub-task that required minimal interaction between participant and client), assessment of client's capability of bathing (a sub-task that required some interaction between participant and client), and assessment of client's capability to perform weight-shifting (a sub-task that required a lot of interaction, questions and answers back and forth between participant and client).

Table 18 Average Time on Task

	VISYTER	POLYCOM	Sig
Total Time	180.79 ± 38.81	238.26 ± 66.80	0.002
Breakdown based on Tasks			
* Task 01: Starting up system	39.47 ± 14.82	75.42 ± 46.84	0.012
* Task 02: Information verification	47.05 ± 20.48	55.74 ± 23.07	0.043
* Task 03: Acquiring new information and storing of information	79.37 ± 26.07	87.79 ± 46.76	0.409
* Task 04: Disconnect and turning off system	14.89 ± 12.31	19.32 ± 9.60	0.002

Table 18 detailed the result of the time on task extraction. Based on the result, the time required to perform the assessment tasks on integrated system ranged from approximately 2 minutes to 3 minutes, while performing similar tasks on non-integrated systems ranged from approximately 2 and half minutes to 5 minutes. On average, performing assessment through VISYTER is significantly faster compared to POLYCOM, with the data showing almost 25% increase in time efficiency. The detailed analysis of the result based on tasks showed significant time difference between the use of integrated system and non-integrated systems in task 1, task 2, and task 4. The study, however, did not find a significant time difference in task 3 acquire and store new information.

Based on observation, participants were able to finish the first task more efficiently in integrated system due to streamlined connection process. In VISYTER, participants were not required to remember and type in the exact internet address of their client. Instead, participants need only to point and click the room icon that would automatically connect them to their client. Although POLYCOM has similar capability in which user could connect using an address book, the system was set by default to ask for an exact internet address. Thus, most participants decided to follow the default option by entering exact internet address without trying to use the address book. The time required to type in the internet address contributed most of the time difference between POLYCOM and VISYTER.

In the second task, VISYTER's interface design allowed participants to complete their tasks more efficiently than POLYCOM. During information verification, participants were required to read the information in their client record, and confirmed the content with the client. VISYTER's integrated videoconferencing with electronic client health record, allowed participants to read the information while maintaining eye-contact with the client. POLYCOM, on the other hand, required participants to switch their attention between videoconferencing system and the paper-based client record.

The study did not find a significant time difference in the third task. The variability of the interaction between each participant with the client was high during the third task, whether through VISYTER or POLYCOM. During this task, participants with more exposure to similar case of the client (client that needed a new mobility device) would perform more detailed assessment compared to participants with less exposure to the client's case. This difference in style impacted the time to complete the assessment, which may had become a confounding factor in analyzing the time efficiency of the system.

Similar to the first task, participants were also able to finish the fourth task more efficiently in integrated system due to streamlined disconnection and shutting down process. As with any Windows-based applications, VISYTER required only one click to completely shut down the system, which was accomplished through clicking the 'x' button at the corner of the application window. POLYCOM required the participant to disconnect from the call by pressing the hang-up button twice on the remote, and turning off the system by physically pressing the power switch.

Zheng, et al. (2010) mentioned workflow fragmentation as a possible cause for reduced efficiency in health information management system. Figure 25 presented a timeline belt visualization of a typical clinician's workflow during an assessment session using VISYTER and POLYCOM. A black bar represented a fragmentation in the clinician's workflow, in which the clinician performed no interaction with the client or the system. Two conditions may cause a fragmentation in the clinician's workflow: switching between tasks and switching between systems. In POLYCOM system, most fragmentations in the clinician's workflow were caused by switching between systems. For example, during an assessment, clinician would be required to read some information about the client in a different system (a paper-based form or a computer). Afterward, the clinician would 'switch' over to the videoconferencing system to verify this information. This process may happen more than once per data item, which increased the time used to perform tasks using POLYCOM. In VISYTER, this fragmentation type was completely eliminated.

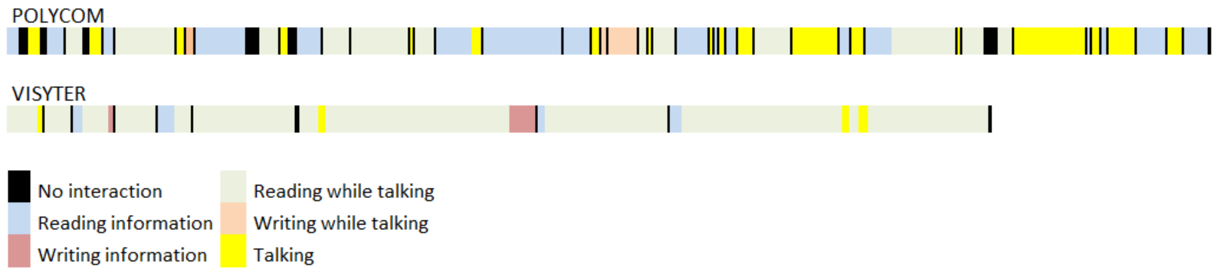

Figure 25 Timeline Belt Visualization of the Workflow

Error Detection

Based on the source of the errors, two types of error event were being identified: errors caused by the user (human errors) and errors caused by a bug in the system (system errors). The common causes for human errors were misconception on how the system worked or failure to recall the correct steps to use the system. For example, an event in which a participant could not recall the location of a button within the interface was considered a human error. Ideally, the system should provide sufficient cues to solve the situation caused by human error. In the case of recall problem, the system should be able to provide a message or a help box to assist user to find the solution to their problem. These errors are usually caused by a poorly designed human-computer interface (Nielsen, 1993). System errors, on the other hand, were errors caused by other factors outside of the human user. The error could be caused by an intermittent error inside the system's code ('bug') or an outside event that caused the system to behave out of expectation. For example, instability in the telecommunication network may produce a disturbance of video or audio during a teleassessment session. Ideally, the system should notify the problem to the user and provided clear suggestions on how to solve the problem.

The error analysis was performed by reviewing all study session records. Each error event found was graded with a severity ranking based on the amount of effort required to recover from the error. Any error that can be recovered with no or minimal participant's intervention was graded as having severity ranking 1, any error that can be recovered by participant with some additional information was graded as having severity ranking 2, and any error that cannot be recovered by participant was graded as having severity ranking 3. Table 19 presented the list of errors, sorted by severity ranking.

Table 19 List of Errors Encountered

VISYTER Description	Rating	POLYCOM Description	Rating
		(PT1S2) System hibernation process caused latency and lag in communication	3
(VT1H1) Participant could not locate the tab to access venue list	2	(PT1H1) Participant did not enter the proper internet address	2
(VT2H1) Participant did not remember the steps to access client information	2	(PT1S1) 'Dot' button at system's remote did not produce dot	2
(VT3H2) Participant did not remember the location of the save button	2		
(VT1H2) Participant entered wrong username and/or password	1	(PT2S2) System detected wrong vocal source	1
(VT2S1) Packet(s) transmitted between site were lost due to network/internet instability	1	(PT2S1) Packet(s) transmitted between site were lost due to network/internet instability	1
(VT3H1) Participant did not remember to save the document	1	(VT4H1) Participant did not disconnect properly	1

Below is the detailed explanation of each error type, ordered by the task that produced the error:

- In task 1, participants that used POLYCOM encountered 2 system errors (PT1S1, PT1S2) and 1 human errors (PT1H1), while participants that used VISYTER encountered no system error and 2 human errors (VT1H1, VT1H2):
  - PT1S1: 'Dot' button at system's remote did not produce 'dot' on screen.
    - Type: system error.
    - Time of occurrence: during the time when participant need to enter internet address; 'dot' was required as the separator between the numbers. For example: '192.168.0.1'.
    - Description: Participant encountered an erroneous mapping of button in which the remote's 'dot' button did not produce a 'dot'. To produce the 'dot', participant had to use the 'right arrow' button instead. The 'dot' button was used to confirm actions.

- Recovery: The system did not tell the user about the mapping of button. Therefore, user had to try each button to find the ‘dot’. Some participants asked for help from researcher to find the dot.
- Severity: 2 – error can be recovered with help.

o PT1S2: System hibernation process caused latency and lag in communication.

- Type: System error.
- Time of occurrence: After dialing to remote site’s system.
- Description: POLYCOM system has the capability to switch into hibernation status after a period of inactivity. The system was designed to switch back into normal status if a call was being received. However, doing so would cause the system to slowdown. The communication would experience a high latency, up to a communication loss.
- Recovery: The system only signaled loss of communication package; however the system could not automatically recover. The only solution was to restart the entire system.
- Severity: 3 – could not be recovered. Only a complete reboot of the system at both sides can solve the problem.

o PT1H1: Participant did not enter the proper internet address.

- Type: human error.
- Time of occurrence: before dialing remote site.
- Description: some participant was not familiar with internet address, and was not able to properly enter the numbers to the system. For example, instead of typing in ‘192.168.0.1’, participant would type in ‘19216801’.
- Recovery: The system would then try to call in the number, even though the number is incorrect. However, the call would fail. The system did not give cue on how to fix the problem. Researcher need to remind the participant on the correct internet address.
- Severity: 2 – error can be recovered with help.

o VT1H1: Participant could not locate the tab to access venue list.

- Type: human error.
- Time of occurrence: before entering the venue.

    - Description: some participants could not recall the location of the tab to access the venue list. Although the problem did not crash the system, without finding the venue list, the participant would not be able to complete the task.
    - Recovery: The system did not provide a cue on the location of the venue list. Some participants were able to find the tab, although the process required them to spend more time than average. Some participants requested a help from researcher to locate the tab.
    - Severity: 2 – error can be recovered with help.
  - VT1H2: Participant entered wrong username and/or password.
    - Type: human error.
    - Time of occurrence: during startup of the application.
    - Description: some participant did not put the correct username and/or password.
    - Recovery: the system provided a message that prompted the user to re-enter their username and/or password.
    - Severity: 1 – error recovered with no/minimal help.
- In task 2, participants that used POLYCOM encountered 2 system errors (PT2S1, PT2S2) and no human errors, while participants that used VISYTER encountered 1 system error (VT2S1) and 1 human error (VT2H1):
  - PT2S1: Packet(s) transmitted between sites were lost due to network/internet instability.
    - Type: system error.
    - Time of occurrence: during communication.
    - Description: during teleassessment session, network instability may cause some packets transmitted to be lost in the network. This event would cause either a disturbance in the video (blocky image) or audio (robotic voice).
    - Recovery: the system would show a lightning symbol on the screen if any packet was lost. Participant must wait for the network to become stable before continuing communication.
    - Severity: 1 – error recovered with no/minimal help.

- PT2S2: System detected wrong vocal source.
  - Type: system error.
  - Time of occurrence: during communication.
  - Description: the system used vocal source detection to reduce echo. The volume of any site that did not produce sound would be reduced to accommodate the site that produced sound. The process of detection was designed to be automatic. However, in some cases, the process detected the wrong sound source, and reduced the volume of the wrong site.
  - Recovery: as the process was automated, the system would dynamically fix the problem in due time.
  - Severity: 1 – error recovered with no/minimal help.
- VT2S1: Packet(s) transmitted between sites were lost due to network/internet instability.
  - Type: system error.
  - Time of occurrence: during communication.
  - Description: during teleassessment session, network instability may cause some packets transmitted to be lost in the network. This event would cause either a disturbance in the video (blocky image) or audio (robotic voice).
  - Recovery: the system would show a message on the window if any packet was lost. Participant must wait for the network to become stable before continuing communication.
  - Severity: 1 – error recovered with no/minimal help.
- VT2H1: Participant did not remember the steps to access client information.
  - Type: human error.
  - Time of occurrence: before starting teleassessment.
  - Description: participant could not recall the exact steps to access the client information. Without access to client information, participant could not start the assessment process.
  - Recovery: the system provided multiple routes to access the information. One link provided direct access to the information from the main page of the portal, however the system lacked cues to point participant to the link.

Some participants required prompting from researcher to recover from the error.

    - <u>Severity</u>: 2 – error can be recovered with help.

- In task 3, participants experienced similar system errors with task 2. In addition, participants that used VISYTER 2 human errors (VT3H1, VT3H2):
  - VT3H1: Participant did not remember to save the document.
    - <u>Type</u>: human error.
    - <u>Time of occurrence</u>: after teleassessment session.
    - <u>Description</u>: some participant did not remember to save the document which contains the information about the assessment.
    - <u>Recovery</u>: the system gave a warning about the document not being saved.
    - <u>Severity</u>: 1 - error recovered with no/minimal help.
  - VT3H2: Participant did not remember the location of the save button
    - <u>Type</u>: human error.
    - <u>Time of occurrence</u>: after teleassessment session.
    - <u>Description</u>: some participant could not recall the location of the save button. In current design, the location of the save button is placed in the top and the bottom part of the electronic document. Participant need to scroll to the top or to the bottom to find the button.
    - <u>Recovery</u>: The system did not provide a cue on the location of the save button. Some participants were able to find the button, although the process required them to spend more time than average. Some participants requested a help from researcher to locate the button.
    - <u>Severity</u>: 2 - error can be recovered with help.
- In task 4, participants that used POLYCOM encountered 1 human error (VT4H1):
  - VT4H1: Participant did not disconnect properly.
    - <u>Type</u>: human error.
    - <u>Time of occurrence</u>: after teleassessment session.
    - <u>Description</u>: to disconnect a session in POLYCOM, participants were required to press the disconnect button twice (one to bring up the session

ending menu, and another one to disconnect the session). Some participants only pressed the button once.

- Recovery: some participant realized that the session did not end and proceeded to disconnect properly. Turning off the system would automatically disconnect the system, however the remote site would experience abrupt ending of session (screen froze for several second before the system decided that the session has been disconnected).
- Severity: 1 - error recovered with no/minimal help.

Based on the severity rate, all human-errors type was categorized as non-critical errors. Most of these errors were caused primarily by lack of familiarity with the system. During the interview, participants expressed that these errors could be easily remedied by providing a simple ‘cheat-sheet’ containing all the frequently asked questions and answers, whether in printed form or electronically.

One system error (PT1S2: System hibernation process caused latency and lag in communication) from POLYCOM was considered to be a critical error. This condition rendered the communication impossible as the latency caused distortion of images and lag in sound. Attempts to restart the process by disconnecting and reconnecting did not change the result. In this condition, the systems at both sides (participant’s and client’s site) needed to be completely turned off and turned back on again.

7.4.2 Preference Metrics

Perceived Usability

The IBM Post-Study System Usability Questionnaire (IBM PSSUQ) was the tool chosen to measure participant's perception of the system's usability. This questionnaire consisted of 19 close-ended questions that were administered after the study. This questionnaire viewed usability of a system from three categories: system usefulness, information quality, and interface quality. System usefulness measures the user's belief in the system to support their tasks while information quality measures the user's belief in the system to provide the necessary information to support their tasks. These two categories measured participant's perception on the effectiveness of the system, efficiency of the system, and the system's capability of error recovery. Interface quality measures the participant's view of the system's logic and flow while using the system's interface. This category also measured participant's satisfaction in using the system.

The result of the questionnaire was a set of quantitative measurements of participant's perception on both systems' usability. Statistical T-test with one within-subject variable was used to analyze the result. Analyses were performed on the overall result (average of the score from all 19 questions) and for each of the three categories. Based on the IBM PSSUQ's manual, the average score from question 1 to 8 measured participants' perception on system usefulness, question 9 to 15 measured participants' perception on information quality, and question 16 to 18 measured participants' perception on interface quality. The level of significance for the test was set at 0.05.

Table 20 Participant's Perception on System Usability Based on IBM PSSUQ

	Integrated - VISYTER (Mean/Std. Dev.)	Non-Integrated - POLYCOM (Mean/Std. Dev.)	Significance
Overall usability	1.68 ±0.58	2.10 ±0.55	0.00
System usefulness	1.67 ±0.64	1.99 ±0.64	0.03
Information quality	1.73 ±0.56	2.14 ±0.70	0.02
Interface quality	1.65 ±0.80	2.18 ±0.80	0.01

The detailed result of the analysis can be found at table 20. The study found a significant difference in the overall usability scores for integrated system (M=1.68, SD=0.58) and non-integrated systems (M=2.10, SD=0.55); t(25)=-3.547, p=0.002. This result suggested that in general, participants considered VISYTER to be more usable than POLYCOM to deliver the teleassessment. A deeper analysis into the three categories of usability showed similar results. In the first category, the system usefulness, participants perceived that both systems were able to support them in completing their tasks, which was shown by the similarity of the scores of integrated system and non-integrated systems (VISYTER=1.67, SD=0.64; POLYCOM=1.99, SD=0.64), although more preference was given to the integrated system, which was reflected by the significance in the difference between the two scores. Participants felt that VISYTER was more proficient (M=1.73, SD=0.56) in providing the necessary information for their tasks when compared to POLYCOM (M=2.14, SD=0.70). In addition, the results shown that participants favored integrated interface layout in VISYTER (M=1.65, SD=0.80) when compared to separated interface used in POLYCOM (M=2.18, SD=0.80).

In-depth Interview

A guided in-depth interview was conducted at the end of each session to investigate further the reasoning behind the questionnaire scores. Each interview lasted between fifteen to twenty minutes. Afterwards, the results of the interview were analyzed to identify unique comments on the system's usability. These comments were then placed into four categories: system's effectiveness; system's efficiency; error and error recovery; and expectation - satisfaction.

System Effectiveness

In general, participants felt that both systems were effective enough to help them conduct their tasks successfully. Several participants liked the simplicity of POLYCOM ("*The system is simple to use since I only need to use a remote. Just like a regular TV set in home*"), however participants preferred the use of VISYTER because of the integration with the electronic health record ("*Although complex, the integrated system brings more information about the client, which allowed me to understand my client's condition in more detail*"). Several participants provided further comments on how important the use of electronic health record in their daily clinic (such as "*Electronic form is the way to go. I don't have to worry about losing the paper or organizing them so I can find them again later. With computer, you just need to access and search for it. It will not be lost*"). Participants agreed that the use of electronic health records allowed clinician to access medical records, history of client, or device specific information anytime during assessment. These tasks (accessing medical records, history of client, or device information during assessment) would not be possible with paper-based forms if such information was not prepared properly beforehand ("*With paper, unless properly prepared, I don’t think therapist can access to medical records, or history of client during assessment*").

Although the electronic health record was deemed to be helpful, participants felt that several user interface components within the form should be refined, including the size of the text area for input ("*Just one line of text area in the electronic form is not enough. I need it to be bigger*"), the position of vertical scroll bar ("*The arrow in the vertical scroll bar is sometime* *obscured in the intake form*"), and the size of the fonts ("*I need the font to be bigger, with bolder color so I can see them easily. It would be better if I can control the size anytime I want by increasing or decreasing the font size*"). Further customizations, such as tooltips and additional information about the terms used in the form, were also being requested to improve the clarity of the information.

Beyond the technology itself, participants' main concern about the system was the cost to deploy the technology. If a clinic or a home setting cannot afford the purchase of the system, then the number of clients to reach is limited and the system might not be sustainable in the long run. Participants felt that the situation would severely reduce the effectiveness of telerehabilitation approach. Participants were deeply concerned about the use of POLYCOM for telerehabilitation due to its cost ("*I don't think I or my clinic will have the money to buy the equipment. I don't think my clients would be able to afford to have one in their homes, either*"). VISYTER, on the other hand, was considered an ideal system for telerehabilitation because of its near-free cost ("*The system -VISYTER- seems to be inexpensive. After all, I just need to have a web camera, since I already have a PC*"). With VISYTER, participants felt that the clinician can perform telerehabilitation anywhere, both in clinic and home settings. Participants agreed that VISYTER allowed better collaboration with other clinicians during an assessment because VISYTER can help them "*talk to many different experts at the same time, connecting from their own PCs*".

One participant described VISYTER as, "*With VISYTER and computer, you can have telerehabilitation anywhere. With this (POLYCOM), you can only have it at clinic*." Furthermore, participants felt that "*VISYTER can be deployed in home setting in fraction of cost" which lend itself to use for "specialized service and in home/natural environment*", especially in limited resource areas. Another participant, who has experience working with individuals with head injury, commented that VISYTER would "*have less psychological disturbance to a client that is already familiar with computer by not introducing new equipment*."

Another barrier to the use of POLYCOM was the terms used in the system. The terms used in POLYCOM's interface was geared for general videoconferencing purposes. For example, the remote site can be dialed by entering 'IP Address'. Many participants understood the concept of 'IP Address' by associating this term with the numbers used to dial in regular phone. However, 'IP Address' required the use of dots ('.'), in which regular phone number does not have. Some participants did not enter the dots because of this misconception about the address. One participant expressed the confusion of the term used in POLYCOM ("*I am not familiar with the language used in the system. Probably because it is not designed for rehabilitation purpose? Either way, I think the clinician has to be trained to even understand the terms used by this system*"). On the other hand, participants felt that the terms used in VISYTER were geared properly to fit into rehabilitation setting

System Efficiency

Participants agreed that integration of features improved efficiency by allowing them to "*do multiple things concurrently*". Having the client information next to the videoconferencing in VISYTER allowed them to easily find and access any information required for the assessment. In addition, participants felt that VISYTER allowed better communication flow ("*I don't have to break my communication with my client to write. I can type while I talk to them, and I can see both at the same time*"). In contrast, participants did not feel that the communication flow would improve with POLYCOM even if the paper based forms were replaced by computer. For example, a participant said that, “t*he use of separate computer would not help. I still need to break the communication to type in the information, since it is not in the same screen*".

Several participants expressed concern with the complexity of the interface. One participant felt overwhelmed with the amount of information presented through VISYTER at any single moment ("*Would all clinicians be able to interact with these many things at once?*"). However, most participants preferred to interact with only single equipment used to run VISYTER (a computer) over multiple equipment of POLYCOM. "*In a way, with the integration of tools, you need to only deal with one system - the PC*". Interacting with VISYTER was deemed as being "*more organized*" as "*everything is in one place*". Interestingly, several participants asked about the possibility of integration during the trial of POLYCOM, prior to using VISYTER.

The use of electronic form was being regarded as a key factor to improve service efficiency. Participants expressed that implementing workflow into the electronic form allowed them "*to know what to do next*" because the terms used "*really mimics (their) daily activities in (their) clinic*". The use of electronic form was more preferred due to several reasons:

- Clinician can concurrently assess the client while recording the result. "Having to write on paper reduce my efficiency because I cannot talk and check on my client in the assessment while I write on paper or read the client's information"
- Clinician can access the information in a faster way. "Imagine if I have an entire wall shelf of client documents. I need to search around first to find the information that I needed. In addition, with paper, I need to flip the paper back and forth to find the information that I want. Which happened in my old office, actually. My new one uses electronic forms, and it is much more efficient."
- Clinician can access more detail about the client. "Paper based approach usually does not have much information about the client. The information is usually not detailed enough."
- Clinician can write in more detailed information. "With pen and paper, I am limited to the space available for me in the paper. Where can I write for some more information?"
- Clinician did not need to transfer or organize the papers manually after the assessment. "Usually, I would not have any more time to transfer the information from paper to computer, so if I can write directly in computer, it would be faster for me."
- Depending on clinician's familiarity with computer application and electronic form, some clinician can enter the information faster. "Overall, I think by now I am slower in writing by hand. I am used to electronic health records in my daily clinic."

In addition, the use of the Internet as VISYTER's platform prompted some participants to comment about the possibility of working remotely. "*With this system I can do more in less time. I can even do my work from home for some cases*". Some participants also expressed that they can prepare themselves better prior to the clinic by reviewing all client information in the online portal through the Internet. "*Being able to access the information from anywhere through internet is very useful as I can review the information prior to clinic*". Furthermore, access to the

Internet was regarded as an important complementary resource to the assessment ("*The use of computer make it possible to access complementary information, such as wheelchair specifications, standardized protocols, reimbursement protocol and many more resources to help with the assessment. I can even access the internet for additional information if necessary*").

Participants provided several recommendations to improve VISYTER's efficiency:

- in regard with VISYTER's user interface:
    - The use of account profile to store information about user's preference ("*It would be better if some automatic setting can be stored based on my profile -the windows positioning, the regular connection that I use etc. , instead of having to set it up again every time*")
    - The addition of shortcuts for most common activities ("*The system is more complex with lots of features and more steps to achieve what I want to do. However, I am very familiar with PC-application, and I know I can make some shortcuts for my common activities later on*"). For example, providing a button to help set up the videoconferencing windows to save time prior to the session ("*Adjusting the windows inside the system take time. Can we have a button to automatically adjust them? I don't really need to see my own camera stream. We really need a shortcut to auto-adjust the window -my client's window should be bigger than me*")
- in regard with the electronic form:
    - The addition of even more details about the client, including the medical history, physician's note, chart review, or history of injury
    - The capability to perform an automatic history/information versioning to trace the condition of a client over time
    - The addition of several information entries, including a free-text field to put the summary of the whole assessment
    - The use of color coding to section the information to improve the clarity of the electronic form
    - Any features to help make typing information faster, such as text auto-completion, smart-text input, or voice recognition

Error, Error Prevention, and Error Recovery

Most comments on errors for POLYCOM were caused by inherent problems of the system. For example, participants complained that they have "*problem with the button mapping*". This problem has been previously reported in section 7.4.1, where the POLYCOM's remote mapped 'dot' character to 'right arrow' button. Some of these problems have been corrected in newer systems, however nothing can be done with an older system because in general, most videoconferencing systems are designed to be used 'as-is' without possibility of personal customization. Another set of problems reported by participants on POLYCOM were on the quality of the video and audio ("*The picture and audio got distorted several times, which made me repeat the questions over and over. It became quite tiring after a while*"). In particular, participants reported that the image was blurry ("*The camera keep on zooming in and out. Can I stop the auto-focus?*") and the audio had echo problem ("*Is there anything we can do with the echo? Sometime the echo really disturbs the assessment*"). Participants felt that these problems were beyond their ability to recover ("*I don't think I can do anything if an error happens. Except rebooting the system, that is*").

With VISYTER, participants felt that most problems and errors were caused by their non-familiarity with the system. For example, two participants expressed to having problem locating list of virtual rooms. ("*I am sure that I need to click on an icon to connect, but I could not find it*"). Participants believed that these problems would be solved in time ("*I need probably need to use the system only a couple times more -three to five times, to get used to the system. I don't need more training*"). Some participants jokingly commented that they "*need to familiarize with typing while talking*" in order to fully utilize all the features of VISYTER.

Participants agreed that the VISYTER's interface design was intuitive ("*Although the system is more complex, it is still very easy to use thanks to the self-describing icons*"). However, participants felt that adding on-screen information/tooltips would help them find features faster ("*I need more guide on the screen -help or something that allows me to find what I need fast. Right now I do not see any*"). Some key interface components also need more detailed information. For example, participants inquired if more detailed information can be added to the list of virtual rooms, such as the name of the participants inside a particular room ("*How do I know which room that my client is in right now? I think the system need to tell me where to go*").

When compared to paper-based forms, the use of electronic forms was being regarded as a better way to prevent error and preserve the integrity of client's information ("*Using computer is better as it can reduce the errors -either from typo or from missing to enter information. Computer can tell if I missed to key in some information*"). Participants agreed that electronic forms "allowed clinician to correct any typo easily" while keeping the information legible ("*If I* *made mistake while writing on paper, I need to cross the item out. Over the time, I think the information would become illegible, unless I transfer it into another paper*"). In addition, participants commented that VISYTER's ability to archive session would be beneficial to help clinician clean up information at later date ("*I would need some kind of recording if I want to clean up the information*").

Expectation and Satisfaction

Most participants were confident in using VISYTER due to their familiarity with computer-based applications ("*I am confident to use the system because I am familiar with PC. The system is easy to use because I am familiar with many computer applications and electronic health records*"). In addition, the authentication process improved participants confident with VISYTER because "*the system feels more secure*".

The use of computer based application prompted several participants to comment about the possibility of using POLYCOM for people "*who are more familiar with TV, but not PC*". At first, these participants felt that the use of one remote control was more straightforward when compared to the use of a computer. However, when presented with the challenges of using POLYCOM, most participants agreed that this benefit (straightforward use) of POLYCOM was not equal with its disadvantages. Several disadvantages of POLYCOM were being considered by participants, including:

- The complexity of the setup ("The POLYCOM system requires user to setup the speaker, turn on the speakers, etc. The other one (VISYTER) does not require me to do anything, since my PC is always on anyway. If everything is already in place, it is easier. But if I need to set up these things myself, it would be hard")
- The videoconferencing system’s remote interface does not add anything to a rehabilitation session ("Too many buttons in the remote might be confusing. Most of them I don’t use anyway")
- The interface of the system felt "old fashioned"

Participants felt that the features of VISYTER were beyond their expectation ("*The system has more features than I expected*"). For example, most participants were surprised to experience the quality of VISYTER's video and audio ("*I didn't know that inexpensive web camera video quality could be this sharp. I can see many details of the client from my* *computer*"). Some participants also preferred the use of VISYTER because the electronic form is similar with their clinical use. Participants also gave positive comments on other features of VISYTER that were not being used as a part of the study, including the capability of archiving a session ("*I like it that the session can be recorded and reviewed, because clinician may not remember exactly what happen during the assessment*") and capability of having multiple cameras and controlling them remotely ("*I like it that this system can control multiple camera. Having multiple camera really helps, especially to view different angle of the client. It helps me understand the client condition better*"). One participant commented on the importance of having multiple cameras in an assessment by saying, "*Single camera is very limiting. It is stationery, and the angle to move the camera is pretty limiting. I couldn't see the entire profile of my client. With additional camera, I can have a more detailed zoom of the client for some assessment.*" However, participants remarked that since VISYTER has so many features and tools, most clinicians need additional training to become familiar with the system. Again, participants responded on the importance of having a simple cheat sheet to operate the system or an on-screen guide for each feature/tool that can be used ("*How about some on screen guide to use each tool?*").

Finally, participants inquired about the possibility of additional features into VISYTER, including:

- Real-time ‘reviewing’ of the session ("Is there a way to pause, and review something that has just happened? It would help in some assessment, I think")
- Interface with other clinical measurement tools ("Can we interface with some tools that has been used to measure the client in our clinic? You know, pressure mapping equipment or something?")
- Private channel between clinician during an assessment for better coordination without interrupting the assessment flow ("Can we have personal/private channel chat between therapists only?")
- Real-time modification of the video being transmitted ("Can we control the brightness/contrast of the video? Sometime, I need more clarity")

7.5 CONCLUSION

The table below (table 21) displays a summary of the study result comparing both VISYTER and the non-integrated systems. High time on tasks and low satisfaction ratings are highlighted in red.

Table 21 Overall Study Result

	Integrated System VISYTER	Non-Integrated Systems POLYCOM	Significance
Performance Metrics			
Task Completion Rate	88%	89.50%	
Time on Task	180.79 ±38.81	238.26 ±66.80	0.002
Preference Metrics			
IBM PSSUQ	1.68 ±0.58	2.10 ±0.55	0.00

The majority of participants found VISYTER to be more efficient, less potential of error, and more satisfying compared to the use of POLYCOM. VISYTER was also deemed to be more versatile due to its use of internet and computer as the platform to run the application. Implementing the recommendations and continuing to work with end-users will ensure a continued user-centered application.

Having an integrated electronic form in the system to access client information was the most important factor to the majority of the participants. The use of integrated electronic form allowed participants to find specific information about the client while simultaneously performing the assessment without breaking the lines of communication. An integrated electronic form was deemed necessary to reduce potential of error and preserve the integrity of client information. In addition, participants felt that the use of centralized site to store the client information would enable experts, local clinicians, and suppliers to have a stronger collaboration, which would produce better service for their clients.

8.0 DISCUSSION

8.1 SUMMARY OF WORK

This dissertation presented a systematic method in developing a platform for telerehabilitation (TR) services. The process began with a review of the current state of TR, which found that most TR solutions depended on non-integrated information technology (IT) systems. These systems may range from a health record system to manage their client's information, a videoconferencing or communication system to discuss events related to an evaluation with an expert, as well as tools used to present test protocol stimuli and capture client responses. The use of non-integrated systems increased the complexity of service delivery in TR because clinicians may need to utilize more than one system at a time to assist their service. This approach required clinicians to spend additional time in training sessions to familiarize oneself with the use of each system individually. In addition, many of these systems were not specifically designed for health or rehabilitation environments. For most clinicians, the use of these systems required them to adapt their service to the limitation of the system. For example, many videoconferencing solutions did not provide multiple camera settings. Clinicians would need to ask their clients to turn around many times to see the activity from multiple angles. Additionally, many TR still utilize separated documentation system, mostly in paper-based format, to archive the information during any TR session. Fitting and integrating these systems into specific requirements of rehabilitation environments generally required resources and expertise that most clinicians or clinics could not afford to have. Overall, these limitations reduced the usability of the systems used to support TR, and thus reduced the adoption of TR into clinical practice.

The usability of a TR system can potentially be improved through the use of an integrated system. An integrated system is an IT platform that has the capability to host/combine all of the tools used in the delivery of the TR. At the Rehabilitation Engineering Research Center on

Telerehabilitation (RERCTR), a model of the platform to support TR was developed to overcome the limitation of non-integrated systems. The model introduced five basic characteristics necessary for an integrated platform: openness, extensible, scalable, cost-effective, and secure. This model is known as the PITT model discussed in Chapter 3. The PITT model was used as the guiding principle in developing a system for the remote wheelchair prescription project (RWP), which process is depicted in figure 26. This project was a TR effort to support clinicians in rural Pennsylvania to prescribe wheeled mobility and seating devices. The process of prescribing wheeled mobility and seating devices required clinicians to assess their clients' conditions, needs, and life settings. This information need to be matched with the proper mobility device to provide the best solution that enabled the client to achieve their goals. In rural clinics with limited expertise in wheeled mobility and seating, TR became an attractive solution which facilitated clinicians to access the knowledge of wheeled and seated mobility experts from assistive technology centers and metropolitan clinics.

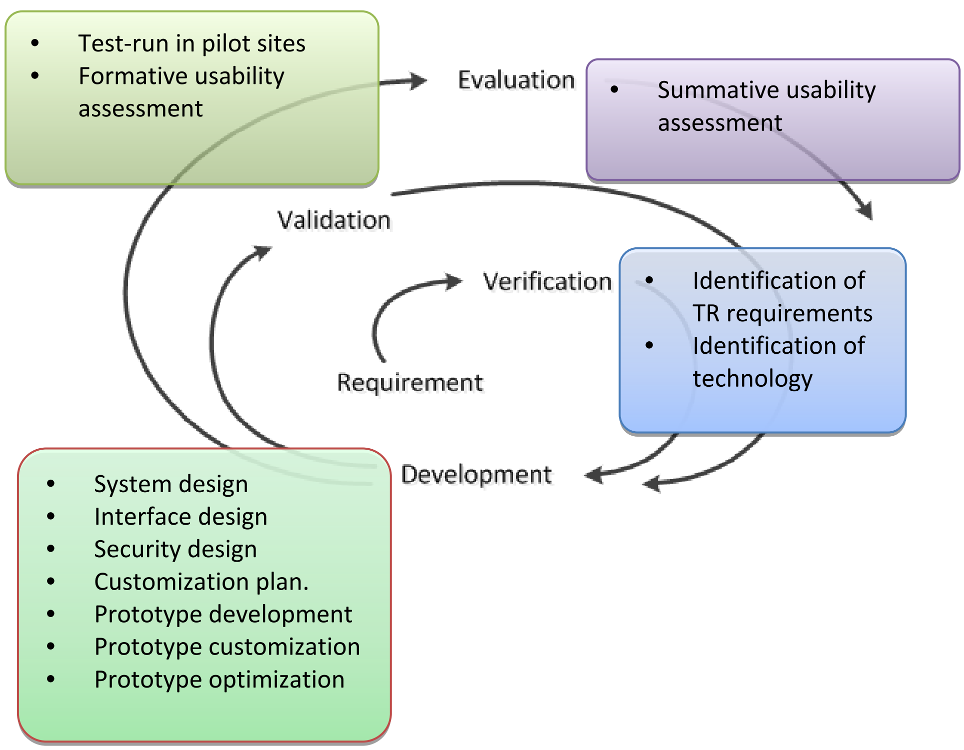

Figure 26 The Spiral Process of the RWP Project

The goals of the system in RWP were to provide real-time (synchronous) teleconsultation communication for clinicians in rural area clinics and support the asynchronous documentation process for prescribing the wheeled mobility intervention. These goals were results from a process of requirement identification and verification, in which a group of clinicians specializing in wheeled and seated mobility were interviewed with the aim of identifying the variables that would be needed to make the telerehabilitation effort successful. The result of the development based on these requirements was a system called VISYTER, a versatile and integrated system for telerehabilitation. VISYTER is a computer-based application on top of the internet which incorporated all five characteristics of the PITT model. Because of these characteristics, VISYTER is easily customized to support any TR, although VISYTER was originally developed using the requirements from RWP.

Validation studies were conducted to ensure that the customization of VISYTER met the requirements of the wheelchair prescription project. Three validation studies were conducted: the first one was conducted after the requirement identification and verification phase, the second one was conducted after prototype development phase, and the third one was conducted after final customization phase of VISYTER. In total, ten individuals, including a physician, clinicians, and rehabilitation technology suppliers participated to validate VISYTER in their workplaces. All participants agreed that VISYTER can be used to properly support both the teleconsultation and documentation phase of RWP.

Afterward, the usability of VISYTER was evaluated by comparing the system with typical non-integrated systems, consisting of a personal videoconferencing system from POLYCOM, television, and paper-based documents. In this study, twenty-six occupational and physical therapists participated in a counterbalanced experimental study to measure the difference in usability for completing client assessment tasks using the integrated and the non-integrated systems. The study was conducted in a laboratory environment. The study found that integration of system improved the efficiency of the system compared to non-integrated system. Participants also responded that they integrated system is easier to use compared to non-integrated system. In addition, participants experiences that the use of a computer based application on top of the internet made VISYTER more versatile (can be deployed anywhere with sufficient internet connection).

In conclusion, the use of PITT model to develop a platform to support TR resulted in an integrated system that is open to various components required for TR service, extensible and easy to customize, scalable to be deployed anywhere at any time, cost-effective, and secure.

Clinicians that participated in the evaluation study considered VISYTER to be more usable when compared to non-integrated systems (POLYCOM). Currently, VISYTER has been adapted by several TR projects outside of RWP, including a tele-neuropsychology project, a remote adult autism assessment project, and an international learning service project. These projects are now being implemented outside the state of Pennsylvania and even outside of the United States.

8.2 POTENTIAL IDEAS TO IMPROVE THE USABILITY OF VISYTER

The ideas to improve the usability of VISYTER were compiled based on the participants feedbacks during both verification and validation study. These ideas are currently being infused to the new development cycle of VISYTER to further refine the system.

8.2.1 Easier Installation and Setup

Most participants viewed VISYTER as a good alternative to save the time required to meet and communicate with clients who have transportation issues and are homebound through TR. In addition, VISYTER was considered to be the best way to communicate with clients that live or are located in remote areas to have to travel to a large metropolitan area for treatment. Participants agreed that this method of communication allowed them to spend less time travelling and decrease their travel costs. In an emergency situation, VISYTER could also become a viable option to communicate with clients or caregivers. However, these advantages of VISYTER would not be realized without an easier installation and setup phase. Participants that installed VISYTER at their desktop suggested an automated approach in setting up VISYTER. For example, instead of manually determining the video quality and the audio quality based on the available bandwidth, participants suggested that VISYTER automatically detected the bandwidth and adjusted the video and audio quality appropriately. Or, as a secondary option, participants suggested a simple ‘wizard-like’ window to help them adjust the setting. For example, the window could ask the type of the connection that the user have, and use a predetermined setting for that specific connection. Participant felt that simplified installation and setup would help clients or caregivers that have little to no knowledge of computer.

8.2.2 Adaptation of Advanced Technologies

Some clinicians were concerned that the current approach of VISYTER might not be enough to capture client's non-verbal information (i.e. smell, condition of device, or client's body language). These clinicians felt that different, advanced technology can be used to add the non-verbal dimension. For example, an addition of client's medical and social history inside the online portal can help clinicians to understand beyond what is being spoken through the communication system (i.e. videoconferencing) itself. Clinicians also mentioned that the medical and social history should be synchronized automatically to the client's main health record information stored in the hospital system to ensure the accuracy of the information, thus ensuring that the information used during the TR session is up-to-date. Another example, information about device history would allow clinicians to arrange appropriate demo equipment for the client to trial instead of having to come back for a second visit.

Clinicians also suggested several other technologies that have the potential to improve the dimensions of TR, including the use of different types of camera to view the client from multiple angles and Universal Serial Bus (USB) based instruments to digitize client's physical condition in real time. For example, the use of USB-based pressure mat would give more information about a client's sitting posture, thus allowing clinicians to recommend a better seating system for the client.

Dictation software was also suggested to improve the usability of VISYTER. Most participants felt that dictation software can improve the efficiency of data entering process. Several dictation applications were suggested by clinicians, including Dragon Naturally Speaking and Microsoft's own speech to text program.

8.2.3 More User Friendly, Context-based Help System

The success of TR depends on the familiarity of the clinician with the technology being used. Most participants were attracted to the use of VISYTER in TR because VISYTER's familiar interface allowed them to perform TR without intensive training session (participants considered VISYTER’s interface to be similar with some other Microsoft products, including Microsoft Words and Excel). These clinicians were comfortable with using a computer application and electronic health records, mostly due to their own exposure to these technologies in their own clinic. However, participants were concerned about the minimal presence of a help system within VISYTER.

Participants suggested two options to improve the help system within VISYTER. The first one is to provide an easy access to an electronic 'cheat-sheet' or ‘frequently asked questions’ to help clinicians remember the step-by-step instructions on how to properly operate the system. The access to these instructions could be in the form of a button to click or a pop-up window at the start-up of VISYTER (which can be deactivated once clinicians become more proficient with VISYTER). The second option is to give a context-based assistance during the operation of VISYTER itself. For example, the addition of auto-completion or term-suggestion during the data entering process would reduce the potential errors from typo.

8.3 BRINGING THE PITT MODEL INTO CLINICAL PRACTICE

The experience of building VISYTER for RWP allowed the formation of a guideline to bring the PITT model into clinical practice. This guideline consists of 4 main phases: design, develop, deploy, and refine ('3DR' approach).

8.3.1 Designing the System for Telerehabilitation

The goal of this phase is to identify the main requirements of TR and design a system to match the requirements identified. The first task that a system developer should do is to understand the context of the service. Specifically, system developer should:

- Identify the importance of the service by answering:
  - What is the goal of the service?
  - What impact would transforming the service into TR bring?

- ❖ Identify the key players of the service by answering:
  - ➢ Who are the clients of the service? What do they need from the service?
  - ➢ Who are the service providers? What do they want to give?
  - ➢ Are there any other stakeholders in this service? If yes, who are they and what are their roles in the service?
- ❖ Identify the mean to deliver the service by answering:
  - ➢ In traditional service delivery model, how does the client receive the service?
  - ➢ What are the tools required to deliver the service?
  - ➢ What are the limitations of access based on the condition of the client?

Afterward, system developer should create a design of the system. This design should:

- ❖ Be open and scalable to add components as needed by TR
- ❖ Have a customizable user interface to meet with the user's need by answering:
  - ➢ What kind of functions that the user need to access from the system?
  - ➢ What kind of display that the user needs to see?
  - ➢ What kind of accessibility option that the user will need to interact with the system?
- ❖ Utilize cost-effective solutions to build the components of the system by answering:
  - ➢ Can commonly available infrastructure be utilized to deliver the service?
  - ➢ Can open-source projects be included to shorten the development time?
  - ➢ Can off-the-shelf equipment be used instead of proprietary equipment?
- ❖ Be able to secure the information being transmitted by answering:
  - ➢ Is there any industrial standard to secure the data transmission?
  - ➢ Can the system utilize well known, verified, and validated technique and algorithm to secure the data through encryption?
  - ➢ What are other security layers that can be added in without burdening the user?

System developer should validate the design to ensure that all requirements and needs have been accounted for. The result of this process should be in the form of a requirements and components matrix, with reference to the initial identified requirements.

8.3.2 Developing the System for Telerehabilitation

In this phase, system developer should work closely with end users during the process to build the prototype of the system. Specifically, in system development phase, developers should:

- ❖ Develop the infrastructure that allows a transformation of service from traditional face-to-face setting into ‘tele’ setting
- ❖ Interface the infrastructure with devices, components, and advanced technologies that allows transformation of analog into digital information
- ❖ Develop a mechanism to allow the infrastructure to stream the information over the distance
- ❖ Develop a mechanism to protect the security and confidentiality of the system by following the industry's security standard and protocol

During iterations of the prototype development, system developers should also include the end users to:

- ❖ Create an intuitive user interface to allow user access to the features of the system
- ❖ Ensure that the transformation of the service maintains the fidelity of the rehabilitation process

This prototype should then be subjected to several pilot studies to ensure that the required features are working as intended. Additionally, the pilot studies should be used to gather information about the potential challenges and limitation from the sites that might prevent a successful deployment of the system in the real world setting.

8.3.3 Deploying the System for Telerehabilitation

The next step in the process is to deploy the developed system on-site. During this step, system developers should work closely with the project champion in each site to ensure the success of the deployment process. Several key issues that should be given proper attention to:

- ❖ Information technology (IT) availability, including:
    - ➢ The design of the local site's network
    - ➢ The availability of bandwidth

    - The availability of technology currently being used on-site
- Personnel/Staff capability, including:
    - The capability of clinicians/service providers who will be using the system
    - The availability of support from local information technology (IT) staff within the organization
- Organizational support, including:
    - The amount of resources allocated to support the TR
    - The availability of spaces for performing TR

8.3.4 Refining the System for Telerehabilitation

The refinement phase focused on improving the usability of the system. In this phase, system developer should conduct a user-centered usability test to identify any usability problems and to investigate potential usability improvements that can be used to refine the system. Specifically, system developer should:

- Conduct a usability study to identify any usability issues within the system, by answering:
    - How effective the system is to support user in performing their activities?
    - How efficient the system is to support user in performing their activities?
    - Are there any errors that prevent the user from completing their tasks? And does the system allow the user to recover from any errors?
    - Is the system easy to use?
    - Does the user like the system?
- Investigate potential usability improvements, by answering:
    - Are there any features that can be developed to allow user perform more activities?
    - Can the system be improved to allow users complete their task faster?
    - Can the system identifies errors and/or helped user recover from those errors easily?
- Validate the findings of the study with the initial goal of the system
    - Does the system allow the project to meet its original goal?
    - Does the system improve the process of delivering rehabilitation service through the help of information technology?

By incorporating the result of this phase into development process, system developer should be able to improve the usability of the system for TR. If the findings identified new requirements beyond the original need, system developer should suggest a new iteration of the 3DR approach in developing the next version of the system.

8.4 FUTURE WORKS

8.4.1 Overcoming the Limitation of the Study

TR is a new and growing field. Each TR project generally uses specific tools and requires specific skillset to perform. The study described in this dissertation used mainly RWP as its 'test bed'. Some of the findings from this study are transferrable to other fields, as is shown by the use of VISYTER in other TR projects. However, due to the uniqueness of each rehabilitation service (most rehabilitation service has its own specific assessment procedures and equipment to identify the client's need), more appropriateness and usability studies need to be conducted with VISYTER. For example, a current research project to assess autism for adults requires the workflow to be adjusted to the proper assessment phases and steps for that specific rehabilitation environment. Electronic forms used in these assessments will be completely different with the one used for RWP, although the method and the tools used to develop the electronic form itself are transferrable across projects.

The use of a lab environment in this study was important to understand the basic needs of telerehabilitation. However, experiments conducted in workplace environment with real assessment and real cases could potentially improve the quality of findings from the usability study for each particular field of rehabilitation. For example, in this study, VISYTER was not used during the home assessment of the client's home. Some very specific problems may arise during this phase, in which device providers would need to communicate with the clinicians to fine tune the equipment properly. During the study, however, setting up VISYTER to be available at the client's house was almost impossible due to the lack of available internet infrastructure in most clients' rural homes.

8.4.2 Potential Future Development for Telerehabilitation

With the advances of higher wireless bandwidth, such as the 4G network, TR can potentially be delivered on top of mobile platforms. VISYTER has been tested to work properly on top of the slate computer, which runs a Windows operating system. Although the existing wireless network (2.5G and 3G) has enough bandwidth to support VISYTER, the stability of the network varies widely from time to time. Each spike and drop in network would result in packet loss, which would make any communication illegible and difficult to understand. The next generation of the wireless network (4G) would provide higher and faster bandwidth, which would hopefully overcome the problem of network stability.

Such network would allow VISYTER to deliver a 'just-in-time' service, in which clients would be able to connect with their clinicians during an incident. This type of TR would be appropriate to support clients in their daily activities, and potentially will allow specific type of rehabilitation, such as job coaching, or providing support for adult with autism. In addition, this network would also overcome the limitation of location to provide service. For example, the study on RWP can easily be extended even to client's home during the delivery of the equipment. Providers of the equipment can connect with the clinicians in both rural clinics and metropolitan clinics should any problem arises during the delivery. Overall, the availability of better network and more affordable, usable TR system may lead to wider acceptance of TR in everyday practice.

APPENDIX A

IBM POST-STUDY SYSTEM USABILITY QUESTIONNAIRE (PSSUQ)

1. Overall, I am satisfied with how easy it is to use this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

2. It was simple to use this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

3. I could effectively complete the tasks and scenarios using this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

4. I was able to complete the tasks and scenarios quickly using this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

5. I was able to efficiently complete the tasks and scenarios using the system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

6. I felt comfortable using this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

7. It was easy to learn to use this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

8. I believe I could become productive quickly using this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

9. The system gave error messages that clearly told me how to fix problems.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

10. Whenever I made a mistake using the system, I could recover easily and quickly.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

11. The information (such as on-line help, on-screen messages, and other documentation) provided with this system was clear.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

12. It was easy to find the information I needed.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

13. The information provided for the system was easy to understand.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

14. The information was effective in helping me complete the tasks and scenarios.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

15. The organization of information on the system screens was clear.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

16. The interface of the system was pleasant.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

17. I liked using the interface of the system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

18. This system has all the functions and capabilities I expect it to have.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

19. Overall, I am satisfied with this system.

	1	2	3	4	5	6	7	
Strongly Agree	□	□	□	□	□	□	□	Strongly Disagree

□ Check for not-applicable

Additional Comments:

BIBLIOGRAPHY

American Telemedicine Association. (2010). A Blueprint for Telerehabilitation Guidelines. American Telemedicine Association: http://www.americantelemed.org/files/public/standards/ATA%20Telerehab%20Guidelines%20v1%20(2).pdf

Anderson, R., Beavers, J., VanDeGrift, T., & Videon, F. (2003). *Videoconferencing and presentation support for synchronous distance learning.* 33rd Annual Frontiers in Education Conference (F3F-18). Boulder, CO.

Anderson, R., Anderson, R., VanDeGrift, T., Wolfman, S., & Yasuhara, K. (2003). *Interaction Patterns with a Classroom Feedback System: Making Time for Feedback.* CHI 2003 Interactive Poster: Conference on Human Factors in Computing Systems. Ft. Lauderdale, Florida, USA.

Batavia, M., Batavia, AI., Friedman, R., (2001). Changing Chairs: Anticipating problems in prescribing wheelchairs. Disability and Rehabilitation, 23, 539-548.

Bashshur, R. L. (2002). *Telemedicine and Health Care.* Telemed J e Health, 8 (1), 5-12.

Bashshur, R., Shannon, G., Sapci., H. (2005). Telemedicine Evaluation. Telemedicine and e-Health., 11(3), 296-316

Bourgeois, M. S., Lenius, K., Turkstra, L., & Camp, C. (2007). *The Effects of Cognitive Teletherapy on Reported Everyday Memory Behaviours of Persons with Chronic Traumatic Brain Injury*. Brain Inj, 21 (12), 1245-1257.

Bunker, E. (2005). Beyond the Spreadsheet: Usability of a Prototype Interface for Accessing and Visualizing Public Health Data. Presentation at the National Library of Medicine Director's Meeting. Bethesda, MD.

Brennan, D. M., Georgeadis, A. C., Baron, C. R., & Barker, L. M. (2004). The Effect of Videoconference-based Telerehabilitation on Story Retelling Performance by Brain-injured Subjects and Its Implications for Remote Speech-Language Therapy. Telemed J E Health , 10 (2), 147-154.

Brennan, D. M., & Barker, L. M. (2008). *Human Factors in the Development and Implementation of Telerehabilitation Systems.* J Telemed Telecare , 14 (2), 55-58.

Burns, R. B., Crislip, D., Daviou, P., Temkin, A., Vesmarovich, S., Anshutz, J., et al. (1998). *Using Telerehabilitation to Support Assistive Technology.* Assistive Technology, 10, 126-133.

Callas, P. W., Ricci, M. A., & Caputo, M. P. (2000). Improved rural provider access to continuing medical education through interactive videoconferencing. Telemedicine Journal and e-Health, 6(4), 393-399.

Cashmore, C., Lyall, R. (1991) Business Information: Systems and Strategies, Englewood Cliffs, NJ: Prentice Hall

Clarke, K., O'Moore, R., Smeets, R., Talmon, J., Brender, J., McNair, P., et al. (1991). A methodology for evaluation of knowledge-based systems in medicine. Lecture Notes in Medical Informatics, 45, 361-370.

Cooper, R., Trefler, E., Hobson, DA. (1996). Wheelchairs and seating: Issues and practices. Technology and Disability, 5, 3-16.

Cooper, R., Fitzgerald, S., Boninger, M., Brienza, D., Shapcott, N., & Cooper, R. A. (2001). *Prolog to Telerehabilitation: expanding access to rehabilitation expertise.* Proceedings of the IEEE, 89, 1172-1173.

Cooper, R., Fitzgerald, S., Boninger, M. L., Cooper, R. A., Shapcott, N., & Cohen, L. (2002). *Using Telerehabilitation to aid in Selecting a Wheelchair.* RESNA 2002 Annual Conference Proceedings. Minneapolis, Minnesota.

Crabtree, A., (2003). *Designing Collaborative Systems: A Practical Guide to Ethnography*, Springer.

Deakin CD, Evans S, & King P. (2010). Evaluation of telephone-cardiopulmonary resuscitation advice for paediatric cardiac arrest. Resuscitation. 2010 Jul;81(7):853-6.

Demiris, G., Shigaki, C. L., & Schopp, L. H. (2005). *An Evaluation Framework for a Rural Home-Based Telerehabilitation Network.* Journal of Medical Systems, 29 (6), 595-603.

Dumas, J. S., & Redish, J. C. (1999). *A Practical Guide to Usability Testing (revised ed.).* Bristol, U. K.: Intellect Books.

Durfee, W. K., Savard, L., & Weinstein, S. (2007). *Technical Feasibility of Teleassessments for Rehabilitation.* IEEE Trans Neural Syst Rehabil Eng, 15 (1), 23-29.

Ede, M. R. (1998). *Focus Groups to Study Work Practice.* Usability Interface, 5 (2).

Engbers, L., Bloo, H., Kleissen, R., Spoelstra, J., & Vollenbroek-Hutten, M. (2003). *Development of a teleconsultation system for communication between physiotherapists concerning children with complex movement and postural disorders.* J Telemed Telecare, 9 (6), 339-343.

Engelbrecht, R., Rector, A., & Moser, W. (1995). Verification and Validation. Assessment and Evaluation of Inform. Technol.

Feng, X., & Winters, J. (2007). *An Interactive Framework for Personalized Computer-Assisted Neurorehabilitation.* IEEE Transactions on Information Technology in Biomedicine, 11 (5), 518-526.

Gentry, T., Wallace, J., Kvarfordt, C., Lynch., KB. (2008). Personal digital assistants as cognitive aids for individuals with severe traumatic brain injury: A community-based trial. Brain Injury 22(1), 19-24

Giansanti, D., Morelli, S., Maccioni, G., & Macellari, V. (2007). *Validation of a tele-home-care for hand-telerehabilitation.* Engineering in Medicine and Biology Society, 2007. 29th Annual International Conference of the IEEE (pp. 3830-3832).

Giansanti, D. M., & Maccioni, G. (2008). *Telemonitoring and telerehabilitation of patients with Parkinson's disease: health technology assessment of a novel wearable step counter.* Telemed J E Health, 14 (1), 76-83.

Goldschmidt, P. G. (2005). HIT and MIS: implications of health information technology and medical information systems. Commun. ACM, 48(10), 68-74.

Hatzakis, M., Haselkorn, J., Williams, R., Turner, A., & Nichol, P. (2003). Telemedicine and the delivery of health services to veterans with multiple sclerosis. Journal of Rehabilitation Research and Development, 40(3), 265-282.

Heinzelmann, P. J., Lugn, N. E., & Kvedar, J. C. (2005). Telemedicine in the future. Journal of Telemedicine and Telecare, 11, 384-390.

Heuser, A., Kourtev, H., Winter, S., Fensterheim, D., Burdea, G., Hentz, V., et al. (2007). *Telerehabilitation Using the Rutgers Master II Glove Following Carpal Tunnel Release Surgery: Proof-of-Concept.* IEEE Transactions on Neural Systems and Rehabilitation Engineering, 15 (1), 43-49.

Hill, A. J., Theodoros, D. G., Russell, T. G., Cahill, L. M., Ward, E. C., & Clark, K. M. (2006). *An Internet-based telerehabilitation system for the assessment of motor speech disorders: a pilot study.* Am J Speech Lang Pathol., 15 (1), 45-56.

Hoenig, H., Sanford, J. A., Butterfield, T., Griffiths, P. C., Richardson, P., & Hargraves, K. (2006). *Development of a Teletechnology Protocol for In-home Rehabilitation.* J Rehabil Res Dev, 43 (2), 287-298.

Holle, R., & Zahlmann, G. (1999). *Evaluation of telemedical services.* IEEE Transactions on Information Technology in Biomedicine, 3 (2), 84-91.

Hughes, J., et al., (1994). *Moving out from the control room: ethnography in system design*, in: Proceedings of the 1994 ACM Conference on Computer Supported Cooperative Work, 1994, pp. 429–439.

Huijgen, B., Vollenbroek-Hutten, M., Zampolini, M., Opisso, E., Bernabeu, M., Van Nieuwenhoven, J., et al. (2008). *Feasibility of a home-based telerehabilitation system compared to usual care: arm/hand function in patients with stroke, traumatic brain injury and multiple sclerosis.* J Telemed Telecare, 14, 249-256.

Jacklin, PB., et al. (2003). Virtual outreach: economic evaluation of joint teleconsultations for patients referred by their general practitioner for a specialist opinion. BMJ 2003. 327:84

Jennett, P., & Premkumar, K. (1996). *Technology-based Dissemination.* Can J Public Health , 87 (Suppl 2), S34-39.

Kaye, H.S., Kang, T., & LaPlante, M.P. (2000). Mobility devices in the United States (Disability Statistics Report No.14) Washington, DC: U.S. Department of Education, National Institite on Disability and Rehabilitation Research.

Kim, J., Brienza, DM. (2006). "The Virtual Reality Telerehabilitation System for Analyzing Accessibility of the Physical Environment: A Field Test," Proceeding of RESNA 29th International Conference. Atlanta, GA.

Kinsella, A. (1998). Home Telecare in United States. Journal of Telemedicine and Telecare, 4, 195-200.

Klein B. et al,. (2010). A therapist-assisted cognitive behavior therapy internet intervention for posttraumatic stress disorder: pre-, post- and 3-month follow-up results from an open trial. J Anxiety Disord. 2010 Aug;24(6):635-44.

Krupinksi, E., Nypaver, M., Poropatich, R., Ellis, S., Safwat, R., & Sapci, H. (2002). Clinical applications in telemedicine/telehealth. Telemedicine Journal and e-Health, 8(1).

Lansdale, M. (1988). *The Psychology of Personal Information Management.* Applied Ergonomics, 19 (1), 55-66.

Lemaire, E., Boudrias, Y., & Greene, G. (2001). *Low-bandwidth, Internet-based Videoconferencing for Physical Rehabilitation Consultations.* J Telemed Telecare ,7 (2), 82-89.

Lemaire, E., Necsulescu, L., & Greene, G. (2006). *Service Delivery Trends for a Physical Rehabilitation Outreach Program.* Disability & Rehabilitation, 28 (21), 1349-1359.

Lewis, J. (1995). *IBM Computer Usability Satisfaction Questionnaires: Pyschometric Evaluation and Instructions for Use.* International Journal of Human-Computer Interaction, 7 (1), 57-78.

Lewis, J. A., Boian, R. F., Burdea, G., & Deutsch, J. E. (2005). *Remote Console for Virtual Telerehabilitation.* Stud Health Technol Inform, 111, 294-300.

Iwatsuki, H., Fujita, C., Maeno, R., & Matsuya, A. (2004). *Development of a telerehabilitation system for training physiotherapists in rural areas.* J Telemed Telecare , 10 (Suppl 1), 51-52.

Madden, M. (2006). "Internet Penetration and Impact." PEW Internet and American Life Project, 2006.

Malagodi, M., Schmeler, M. R., Shapcott, N. G., & Pelleschi, T. (1998). *The Use of Telemedicine in Assistive Technology Service Delivery: Results of a Pilot Study.* Technology: Special Interest Section Quarterly , 8 (1), pp. 1-4.

McCue, MJ., Palsbo, SE., (2006). Making the Business Case for Telemedicine: An Interactive Spreadsheet. Telemedicine and e-Health, 12(2), 99-106

McCue, MJ., & Palsbo, SE. (2006). Making the Business Case for Telemedicine: An Interactive Spreadsheet. Telemed and e-Health. 12(2):99-106

McCue, M., Hodgins, J., LoPresti, E., & Bargteil, A. (2008). Telerehabilitation in employment/community supports using video-based activity recognition. Telemedicine and e-Health, 14(58).

Morland LA. et al., (2010). Telemedicine for anger management therapy in a rural population of combat veterans with posttraumatic stress disorder: a randomized noninferiority trial. J Clin Psychiatry. 2010 Jul;71(7):855-63.

Neale, D. C., Carroll, J. M., & Rosson, M. B. (2004). *Evaluating Computer-supported Cooperative Work: Models and Frameworks.* Proceedings of the 2004 ACM Conference on Computer Supported Cooperative Work, November 06 - 10, 2004 (pp. 112-121). Chicago, Illinois, USA: ACM, New York.

Nielsen, J. (1993). *Usability Engineering*. Academic Press. ISBN 0-12-518405-0.

O'Leary, D. E. (1993). Verifying and Validating Expert Systems: A Survey. In Expert Syst. Business and Finance: Issues and Applications.

Pakyurek M, Yellowlees P, Hilty D. (2010). The child and adolescent telepsychiatry consultation: can it be a more effective clinical process for certain patients than conventional practice? Telemed J E Health. 2010 Apr;16(3):289-92.

Pare, G., Jaana, M., Sicotte, C. (2007). The Practice of Informatics: Review Paper: Systematic Review of Home Telemonitoring for Chronic Diseases: The Evidence Base. JAMIA, 14, 269-277

Parmanto, B., Saptono, A., Murthi, R., Safos, C, and Lathan, C. (2008) "Secure Telemonitoring System for Delivering Telerehabilitation Therapy to Enhance Children's Communication Function to Home", Journal of Telemedicine and E-Health, Nov;14(9):932-8

Parmanto, B., Saptono, A. (2009). Telerehabilitation: State-of-the-Art from an Informatics Perspective. International Journal of Telerehabilitation, 1(1)

Phillips, V. L., Temkin, A., Vesmarovich, S., & Burns, R. (1998). *A Feasibility Study of Video-based Home Telecare for Clients with Spinal Cord Injuries.* J Telemed Telecare, 4 (4), 219-223.

Phillips, V. L., Temkin, A., Vesmarovich, S., Burns, R., & Idleman, L. (1999). *Using Telehealth Interventions to Prevent Pressure Ulcers in Newly Injured Spinal Cord Injury Patients Post-Discharge.* International Journal of Technology Assessment in Health Care , 15 (4), 749-755.

Piette, J. D., Gregor, M. A., Share, D., Heisler, M., Bernstein, S. J., Koelling, T., et al. (2008). *Improving Heart Failure Self-management Support by Actively Engaging Out-of-home Caregivers: Results of a Feasibility Study.* Congest Heart Fail, 14 (1), 12-18.

Pinelle, D., Gutwin, C. (2006). Loose Coupling and Healthcare Organizations: Deployment Strategies for Groupware. Comput. Supported Coop. Work 15, 5-6, 537-572.

Piron, L., Turolla, A., Tonin, P., Piccione, F., Lain, L., & Dam, M. (2008). *Satisfaction with Care in Post-stroke Patients Undergoing a Telerehabilitation Programme at Home.* J Telemed Telecare , 14 (5), 257-260.

Placidi, G. (2007). *A smart virtual glove for the hand telerehabilitation.* Computers in Biology and Medicine, 37 (8), 1100-1107.

Rabinowitz, T., Murphy, KM., Amour, JL., Ricci, MA., Caputo, MP., Newhouse, PA. (2010). Benefits of a Telepsychiatry Consultation Service for Rural Nursing Home Residents. Telemedicine and e-Health. January/February 2010, 16(1): 34-40.

Randall, M., Kilpatrick, K. E., Pendergast, J. F., Jones, K. R., & Vogel, W. B. (1987). Differences in patient characteristics between Veterans Administration and community hospitals Medical Care, 25(11), 1099-1104.

Ricker, J., Rosenthal, M., Garay, E., DeLuca, J., Germain, A., Abraham-Fuchs, K., et al. (2002). *Telerehabilitation Needs: A Survey of Persons with Acquired Brain Injury.* The Journal of Head Trauma Rehabilitation, 17 (3), 242-250.

Rosen, M. J., Lauderdale, D., & Winters, J. M. (2002). *Summary of the State of the Science Conference on Telerehabilitation.* In J. Winters, C. Robinson, & R. Simpson (Eds.), Emerging and Accessible Telecom. (pp. 220-245). Arlington: RESNA Press.

Russel, T. G. (2007). *Physical Rehabilitation Using Telemedicine.* J Telemed Telecare, 13 (5), 217-220.

Sabharwal, S., Mezaros, M., & Duafenbach, L. (2001). Telerehabilitation across the continuum of care for individuals with spinal cord injury. Paper presented at the Proceedings of the State of the Science Conference on Telerehabilitation.

Saptono, A., Schein, R. M., Parmanto, & B., Fairman, A. (2009). Methodology for Analyzing and Developing Information Management Infrastructure to Support Telerehabilitation. International Journal of Telerehabilitation. 1(1). Retrieved from http://telerehab.pitt.edu/ojs/index.php/Telerehab/article/view/6012

Sanford, J. A., Griffiths, P. C., Richardson, P., Hargraves, K., Butterfield, T., & Hoenig, H. (2006). *The Effects of In-Home Rehabilitation on Task Self-Efficacy in Mobility-Impaired Adults: A Randomized Clinical Trial.* J Am Geriatr Soc, 54 (11), 1641-1648.

Savard, L., Borstad, A., Tkachuck, J., Lauderdale, D., Conroy, B., (2003). Telerehabilitation consultations for clients with neurologic diagnoses: Cases from rural Minnesota and American Samoa. NeuroRehabilitation, 18(2), 93-102

Scotch, M., Parmanto, B., Monaco, V. (2008) Evaluation of SOVAT: An OLAP-GIS decision support system for community health assessment data analysis. BMC Med Inform Decis Mak, 8 (22).

Schein, RM. (2009). Evaluation of a Telerehabilitation Consultation Model for Remote Wheelchair Prescription (Doctoral dissertation, University of Pittsburgh, 2009). Retrieved from http://etd.library.pitt.edu/ETD/available/etd-04172009-090925/

Schopp, L. H., Hales, J. W., Quetsch, J. L., Hauan, M. J., & Brown, G. D. (2004). Design of a peer-to-peer telerehabilitation model. *Telemedicine Journal & eHealth*, *10*(2), 243-251.

Seelman, K. D. (1996, October 30). *Rehabilitation Engineering: Today's Solutions, Tomorrow's Challenges.* Switzer Lecture: http://www.ncddr.org/speeches/seelman961030.html

Seelman, K., Hartman, L. (2009). Telerehabilitation: Policy Issues and Research Tools. International Journal of Telerehabilitation, 1(1)

Shapiro, C., Varian, H. (1999). Information Rules: A Strategic Guide to the Network Economy. Harvard Business School Press

Sugarman, H., Dayan, E., Weisel-Eichler, A., & Tiran, J. (2006). The Jerusalem TeleRehabilitation System, a New Low-cost, Haptic Rehabilitation Approach. Cyberpsychol Behav. , 9 (2), 178-182.

Tan, J. K. (1998) Health Management Information System: Theories, Methods and Applications, Gaithersburg. MD: Aspen Publishers.

Tashakkori, A., & Teddlie, C. (1998). *Mixed Methodology: Combining Qualitative and Quantitative Approaches.* Thousand Oaks, CA: SAGE.

Theodoros, D. (2008). *Telerehabilitation for Service Delivery in Speech-Language Pathology*. J Telemed Telecare , 14 (5), 221-224.

Torsney, K. (2003). *Advantages and Disadvantages of Telerehabilitation for Persons with Neurological Disabilities.* NeuroRehabilitation, 18, 183-185.

Weng, C., McDonald, D.W., Sparks, D., McCoy, J., Gennari, J.H. (2007). *Participatory design of a collaborative clinical trial protocol writing system.* international journal of medical informatics, 76(S), S245–S251

Wainhouse Research. (2006). The ISDN to IP Migration for Videoconferencing. Retrieved from: http://www.wrplatinum.com/Content.aspx?CID=6128

Wakeford, L., Wittman, P. White, M.W., Schmeler, M. (2005). *Telerehabilitation Position Paper*. The Free Library. Retrieved October 22, 2010 from http://www.thefreelibrary.com/Telerehabilitation position paper.-a0208275836

Watts, L., & Monk, A. (1996). *Inter-personal Awareness and Synchronization: Assessing the Value of Communication Technologies.* International Journal of Human-Computer Studies , 44, 849-873.

Winters, J. M. (2002). *Telerehabilitation Research: Emerging Opportunities.* Annu. Rev. Biomed. Eng., 4 (August 2002), 287-320.

Winters, J., Feng, X., Wang, Y., Johnson, L., & Foil, J. (2002). *Rehabilitative Telehealthcare Anywhere: Was the Homecare Technologies Workshop Visionary?* In J. Winters, C. Robinson, & R. Simpson (Eds.), Emerging and Accessible Telecom. (pp. 95-111). Arlington: RESNA Press.

Winters, J., Feng, X., Wang, Y., Johnson, L., & Foil, J. (2004). *Progress Toward Universal Interface Technologies for Telerehabilitation.* Conf Proc IEEE Eng Med Biol Soc., 7, pp. 4777-4780.

Wollinksky, F. D., Coe, R. M., Mosely, R. R., & Homan, S. M. (1985). Veteran's and no veterans' use of health services. Medical Care, 23(12), 1358-1371.

Zeng, X. (2004). Evaluation and Enhancement of Web Contect Accessibility for Persons with Disabilities. Pittsburgh, PA: Health Information Management, University of Pittsburgh.

Zheng, K., Haftel, H.M., Hirschl, R.B., O'Reilly, M., Hanauer, D.A. (2010). Quantifying the impact of health IT implementations on clinical workflow: a new methodological perspective. J Am Med Inform Assoc, 17, 454-461