Emerging Personalized Home Rehabilitation: Integrating Service with Interface

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1. INTRODUCTION

As seen in other chapters in this book, there are many strategies for enhancing access to medical devices (e.g., Chapters pt4_Winters, pt2_Erlandson, pt3_Gardner-Bonneau). Two pillars are approaches that are motivated by *universal design* applied to products (e.g., Chapters pt2_Story, pt2_Erlandson, pt2_Smith) and approaches motivated by *personalized interfaces* supported by standards (e.g., Chapters pt4_Gilman, pt4_Danturthi). The latter approach seems synergistic with a vision of the future shared by many with a vested interest, ranging from researchers to venture capitalists: *personalized medicine*. This article describes the type of emerging technical infrastructure that could make access a reality for a specific target area: *home rehabilitation*.

Historically, rehabilitative therapy has followed conventional reimbursement protocols, implemented primarily through both inpatient and outpatient programs. These programs tend to be semi-personalized, based on implementing a plan for intervention for a specific patient that is based on an initial diagnosis and prognosis, and hopefully ongoing assessments of progress. This is especially true for patients who have access to an inpatient phase. But because of limited resources, these programs have become shorter in duration. Patients are also encouraged to make progress on their own, typically while at home and perhaps with assistance from a home caregiver. At this stage the individual is no longer participating in the role of patient, nor as a consumer of services since there are none to be consumed.

For certain types of rehabilitation, such as after soft tissue injuries or orthopedic surgery, this service delivery model often works – the mix of spontaneous healing supplemented by mild interventions is sufficient. Outpatient or home visits of 2-3 per week are adequate. But for areas such as neurorehabilitation, there is mounting scientific evidence that suggests this is a suboptimal approach. For instance, for individuals recovering from stroke, evidence has accumulated related to neural plasticity and brain reorganization mechanisms that suggests a need for more intensive and/or longer-term rehabilitation. This has motivated the development of new approaches toward neurorehabilitation. These alternatives often make use of technologies based on tools from the robotics and virtual reality fields that help automate aspects of the therapeutic process. Studies using the most notable of these approaches have shown positive results. Yet the technologies are expensive, and access is currently limited to small geographic regions of the country. Some research groups, including the authors', are now actively exploring alternative approaches that strive to reduce access barriers such as cost and distance by taking advantage of emerging trends and advances in mass-market telecommunications and information technologies (E&IT). The trend is also toward more home-centered approaches. But currently, an individual with, for instance, stroke-induced disability lacks access to more personalized interventions.

There are a number of challenges that the authors' group and others face:

- ***Lack of personalized healthcare services:*** No two people are exactly alike, especially when it comes to rehabilitative medicine. However, the paradigm of "one size fits all" rehabilitation is still common, for reasons such as lack of sufficient scientific knowledge of a better alternative, limited resources for therapy and ongoing timely assessments, and a shortage of implementation tools that are engaging and/or client-appropriate.
- ***Limited methods for addressing low access of clients to timely services or researchers to timely research data***. One possibility is a telerehabilitation link that can provide both patients with rehabilitative services and researchers to subject populations. It helps minimize the barrier of distance, and this enhanced access opens up new possibilities for discovering and implementing optimized intervention strategies across the continuum of care. Advances in E&IT hold considerable promise for new telerehabilitation applications.
- ***Lack of effective human-technology interfaces***, or in some cases human-technology-human interfaces, especially for an interface that uses the personal computer and emerging E&IT and interface standards to help implement assessment and therapy programs.

This chapter presents first, scientific findings in neurorehabilitation research field in the last decade, and then state-of-the-art advances in E&IT and human-technology interfaces for the home environment. Finally, a home-based neurorehabilitation platform, which was implemented by the authors' group, is presented as an example.

2. BACKGROUND

Consider one example population where a more personalized form of home-based rehabilitation holds great promise: the estimated 4 million individuals with stroke-induced disability in America who live with various degrees of functional impairment [1]. Over the past decade, as the duration of reimbursed therapy has decreased due to economic pressures on the U.S. health care system, individuals have been discharged well within the range of time where even spontaneous recovery still can be expected. The burden for healthcare services has thus shifted toward outpatient and home visits, where distance can be a barrier. While a challenge, this shift also provides an opportunity – for instance, 100 experts at a Workshop on Home Care Technologies for the 21st Century strongly recommended movement toward a consumer-oriented healthcare system that integrates tele-supported home self-care into the mix [2, 3]. However, little is known about outcomes of consumer-oriented healthcare systems integrating tele-supported home self-care.

Currently, numerous therapeutic techniques for upper-extremity stroke rehabilitation are being implemented in research environments, with much of the excitement initially motivated by the concepts of "learned nonuse" [4] and "forced use" [5]. Subsequent findings show that a few weeks of intensive Constraint-Induced Movement Therapy (CI-Therapy) produced significant improvements in limb use for motivated subjects meeting certain post-stroke criteria [6].

Other therapeutic approaches, such as robotic-assisted therapy, also have shown that significant improvements in function are possible even years after the initial stroke. Reviews of stroke rehabilitation interventions describe robot-assisted therapy as one of the most promising interventions for upper limb therapy [7]. One of the better known is the MIT-MANUS two-degree-of-freedom manipulator with low intrinsic end-point impedance, now sold commercially, which allows the device to measure free movements as well as guide weak limb movements. It uses simple video games to help engage subjects in therapy, based on a research study showing that after 5 one-hour sessions per week for 5 weeks, experimental subjects had greater gains in strength, reduced upper extremity impairment that was still significant in a 3-year follow-up, and greater recovery of functional independence [8]. Another study, with different robotic manipulators and protocol, have shown that compared to conventional sessions, a robot group had larger improvements in a clinical motor impairment scale, strength, and reach [9]. Other studies are exploring virtual reality as a training tool in stroke rehabilitation [10, 11]. Virtual reality is computer technology that simulates real-life learning and allows for increased intensity of training while providing augmented sensory feedback.

What are the lessons of these scientific findings? In 2001, a Workshop on Innovations in Neurorehabilitation at Marquette University brought together engineering and clinical representatives from key research groups involved in innovative technological and robotic therapy clinical trials [12]. Some conclusions drawn by the workshop and from a diversity of existing scientific literature are listed below.

- For brain reorganization, rehabilitative intervention should be *varied*, not just repetitive. Changes in motor cortex are driven by acquisition of new motor skills, not simply motor use.
- Most rehabilitation experts agree that *motivation* has an important role in rehabilitation.
- The best form for stroke therapy remains illusive.
- The optimal timing for intervention remains illusive.
- There is great potential for home rehabilitation, when an appropriate support system is available.

To summarize, there is a great need to develop and implement a consumer-centered, alternative therapeutic strategy for neurorehabilitative therapy that can be accepted and adapted for the home environment. For this strategy to work, it is suggested that *the technology must fit the user*, i.e. be personalized to their abilities, preferences and therapeutic needs. Additionally, the individual user needs access to a support network that includes a practitioner, especially as related to making timely assessments that can help tune subsequent assessments. A key challenge relates to how to design such personalized systems that integrate considerations of a cost-effective service with a user-effective interface, as universal access is a function of cost as well as the design of the interface.

3. DELIVERY METHODS FOR FUTURE HOME REHABILITATION

3.1 TELEREHABILITATION - ADDRESSING THE ACCESS BARRIER OF DISTANCE

As seen in Figure 1, the home rehabilitation process has structural similarities to the classic engineering optimization problem [13]. The specific aim is to design an optimal “treatment plan” (algorithm) and to implement this plan as a collection of “therapeutic interventions” (controls). The processes of “diagnosis,” “prognosis” and “treatment plan” could be put under the umbrella, “personalized rehabilitation”, which means these processes would be customized to an individual’s dynamic system and personal demand.

Ideally, the optimal strategy may change based on sampling of interventions (e.g., to check for compliance) and the ongoing status of the person (e.g., making assessments). A telereahabilitation link makes possible better and more frequent sampling of the health and functional status of the person. Consider the conceptual models of telerehabilitation service delivery [3]:

- *Teleconsultation*: standard “face-to-face” telemedicine model using interactive videoconferencing, typically with high bandwidth between sites.
- *Telehomecare*: often uses a tele-nurse coordinating service delivery, typically with a low- or moderate-bandwidth interactive connection.
- *Telemonitoring*: unobtrusively monitors patient data remotely, with possible interactive teleassessment.
- *Teletherapy*: patient “plays” or “exercises” in the home environment, and therapist has the ability to change settings remotely based on patient’s performance.
- *Telecooperation*: by using the telerehabilitation link, multiple persons can cooperate together to accomplish a goal-directed task. Some experts suggest that this novel model, with its kind of team-work activity, will enhance the motivation of persons at both ends and thus optimize the rehabilitation outcomes.

Advances in E&IT as well as emergence of ubiquitous computing and smart wearable devices are enabling personalized healthcare services to be delivered to individuals at any place and any time. In a ubiquitous computing home environment, computing entities (ranging from sensors, actuators, and devices to Web services and applications) are scattered in different spaces and serve people even without their awareness. For example, a wearable health monitoring device can sample one’s blood pressure, temperature, heart rate and so on; the home patient can use some exercise devices, the setting of which can be remotely set by telepractitioner; Web services can intelligently adjust the exercise plan of the patient.

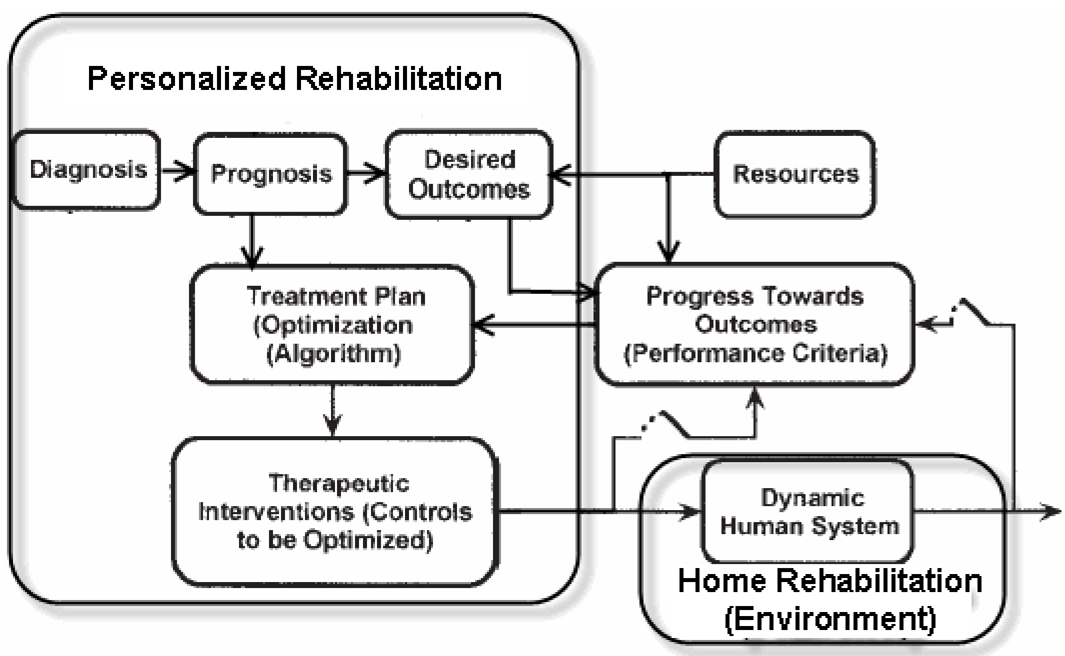

Figure. 1. Overview of the process of home rehabilitation from an “optimization” perspective. A person enters this process with a “diagnosis” (classification) related to a disease and/or functional impairment (the states of the dynamic human system). This diagnosis results in a “prognosis” (prediction of dynamic human system behavior) and desired “outcomes.”

3.2 PERSONALIZED REHABILITATION SERVICES

Personalized healthcare provides medical services that are truly effective for “you.” This ensures that healthcare services provisioned for an individual are *customized* to his/her prevailing healthcare needs. With personalized healthcare, we also have the opportunity to achieve a more “proactive” system where disease can be addressed and hopefully prevented at the earliest possible moment, rather than a “reactive” model where the emphasis is mainly on diagnosis and treatment [2].

The recent popularity of the idea of “personalized medicine” is partly due to the advent of the genomic revolution. Scientists are now avidly seeking correlations between human diseases (e.g., diabetes, hypertension, Alzheimer’s disease) and the architecture of individual genes so as to develop more personalized interventions. For example, in the Milwaukee area, the Medical College of Wisconsin (MCW) has already launched the Individualized Medicine Institute (IMI) to pursue genetic research and translate basic research to more personalized clinical medicine.

Both a patient and practitioner can benefit from personalized rehabilitation. To achieve personalized healthcare, in addition to phenotypic and genotypic patient data, many other factors can be considered. Patient data such as an individual’s diet, living conditions, device capabilities, event occurrences, should be taken into account. Such personalization factors are known as *context*, which refers to any information that can be used to characterize the situation of an entity (can be personal, environmental or computational objects) and the interaction between them [14]. It is well established in the intelligent systems community that a key barrier to intelligent use of information is context-awareness; thus, one of the steps to implementing personalized healthcare is context-awareness. For example, in the authors’ group a neuro-fuzzy modeling framework is developed; if carefully designed with sufficient expert knowledge and/or scientific evidence, it is able to make predictions or real-time estimations of context. The latter is intended to provide context-awareness of a changing context [15].

3. 3 PERSONALIZED ACCESS THROUGH WEB SERVICES

The current societal investment in E&IT is unprecedented. It would be advantageous for rehabilitation to take advantage of this multi-billion-dollar investment by performing concurrent research that anticipates future mass-market technology developments. There are four basic modes of human telecommunication: voice, video/images, data exchange, and virtual contact. Telecommunication technology has experienced dramatic growth in the past few years. In August 2005, broadband penetration exceeded 60% in the US among active Internet users [16]. Penetration is even higher for Japan and much of Europe, and growing dramatically in other countries. The wireless network is increasingly able to carry data: currently in the US it is easy to reach 19.2 KHz data rates, with some phone companies offering about 100 KHz; new mobile tools (e.g., camera phone, blackberry) are becoming more popular. All these technological advances hold promise as constituting a societal infrastructure for launching novel telerehabilitation applications.

Of special interest is the Internet as an emerging collection of standards that enable Web services, including services that inherently promote accessibility, which is based on top of Extensible Markup Language (XML) and related technologies (see also Chapters pt2_Gilman, pt2_Brewer). XML, which was developed by the World Wide Web Consortium (W3C) in 1996, provides a framework for defining markup languages. Beyond XML, "the XML family" is a growing set of modules that offer useful services to accomplish important and frequently demanded tasks [17, 18, 19, 20, and 21]. More and more modules and tools are available or under development. In the past few years, Web services have emerged as the next generation of web-based technology for exchanging information and providing services. This growth is being powered by the program-to-program communication model of web services built on existing and emerging standards such as HyperText Transfer Protocol (HTTP), Simple Object Access Protocol (SOAP), Web Services Description Language (WSDL), and the Universal Description, Discovery, and Integration (UDDI) technologies. The latter three are all XML-related technologies.

A *web service* performs a specific task or a collection of tasks through an *interface* that describes a collection of business operations that can be accessed through standardized XML messaging by network [22]. As shown in Figure 2, three key processes are involved in this service-oriented architecture: first, a Web service is described using a standard, formal XML language expressed in WSDL, called its *service description*, that provides all of the details necessary to interact with the service; the service provider then publishes the service with a service directory based on a UDDI specification which will provide the service consumer with information that can be used to directly bind to the service provider and invoke it; on top of the networking layer is an XML-based messaging layer (in SOAP) that facilitates communications between service provider and service consumer. SOAP is an XML-based messaging layer protocol for messaging and remote procedure calls (RPCs).

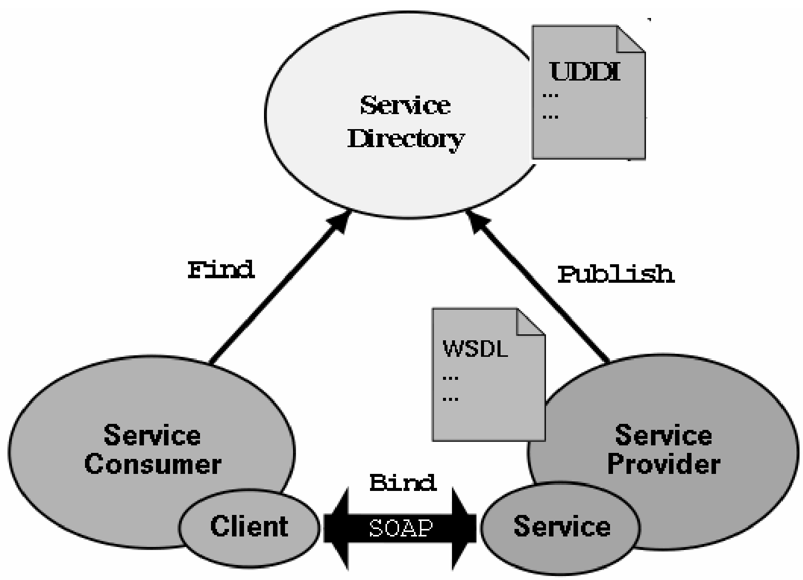

Fig. 2. Web services can be described in terms of a service-oriented architecture. This architecture is set up by three roles and three operations. The three roles are the service provider, the service consumer, and the service directory, and the operations performed on/between the three roles are publish, find, and bind.

So how can the XML-related technologies and a Web-service model benefit home rehabilitation applications? Here are a few compelling reasons to consider:

- ***Collaborations:*** Using Web services, the business logic of individual systems can be exposed over the Web and service can be delivered in the standard communication protocol (e.g., SOAP). In the rehabilitation field, this can enable different participants in the home rehabilitation process (e.g., patient, physical therapist, rehabilitation engineer) to collaborate. For example, a home patient can send his or her vital sign data to the service subscriber, which could be their physical therapist who can adjust their exercise plan, while the rehabilitation engineer will be able to update the algorithm used in the home exercise machine based on the latest scientific findings.

- ***Easy to access:*** Web services published in the UDDI registry and advertised in the WSDL description can be searched by a machine-agent, similar to the manner in which Google searches through Web pages today. Thinking of healthcare more as a “service,” this could profoundly change the medical model used in today’s society.
- ***Ubiquitous:*** Because Web services are provided over the Internet and use existing infrastructure, they are potentially accessible from anywhere. Advances in wireless telecommunication and mobile technologies are speeding this process. Furthermore, because of the standards with which they are developed, Web services respect existing security systems such as firewalls. Further discussion of ubiquitous computing follows in Section 3.4.
- ***Semantic Web:*** This emerging vision is "an extension of the current Web in which information is given well-defined meaning, better enabling computers and people to work in cooperation” [23; pt2_Brewer]. The evolution of the Web into a semantic Web will result in information which is presented in a way that it can be “reprocessed” by intelligent agent. Searches and activities only performed by Web experts today may be commonplace for everyone with the assistance of intelligent agents [24].
- ***Health Information Standards:*** Most of the information standards in different application fields have been influenced by the XML standard. For instance, two examples in the healthcare field are Health Level Seven (HL7) [25] and Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT) [26]. HL7’s domain is to: "…*provide standards for the exchange, management and integration of data…”*.The upcoming Version 3 uses only XML encoding.

3.4 PERSONALIZING HEALTHCARE THROUGH UBIQUITOUS HOME ENVIROMENT TECHNOLOGY

The word “ubiquitous” comes from Latin and means existing universally everywhere, evenly and simultaneously. As shown as Figure 3, in a ubiquitous computing home environment, computing entities (e.g., audiovisual system, intelligent appliance, sensors, and home exercise equipment) are supposed to scatter in different spaces and serve people even without their awareness. Many of those entities can be put into one of two categories: sensors or actuators, which are the primary concerns of home rehabilitation applications. Smart wearable devices (sensors) and gaming technology devices (actuators) are used as examples discussed in this section. Home network infrastructure, including both hardware (e.g., wired or wireless network) and software (e.g., middleware platform), provide a platform for sending data between human and environment, and appropriately processing, storing, and presenting such data [27]. Another consideration is that user interfaces of computer entities at home need to be more user-centered, and support user preferences [28]. It will be critical to generate human-technology interfaces that are sensitive to a client’s capabilities and personal preferences, taking advantages of innovation in universal interfaces, intelligent agents and other state-of-the-art user interface standard technologies.

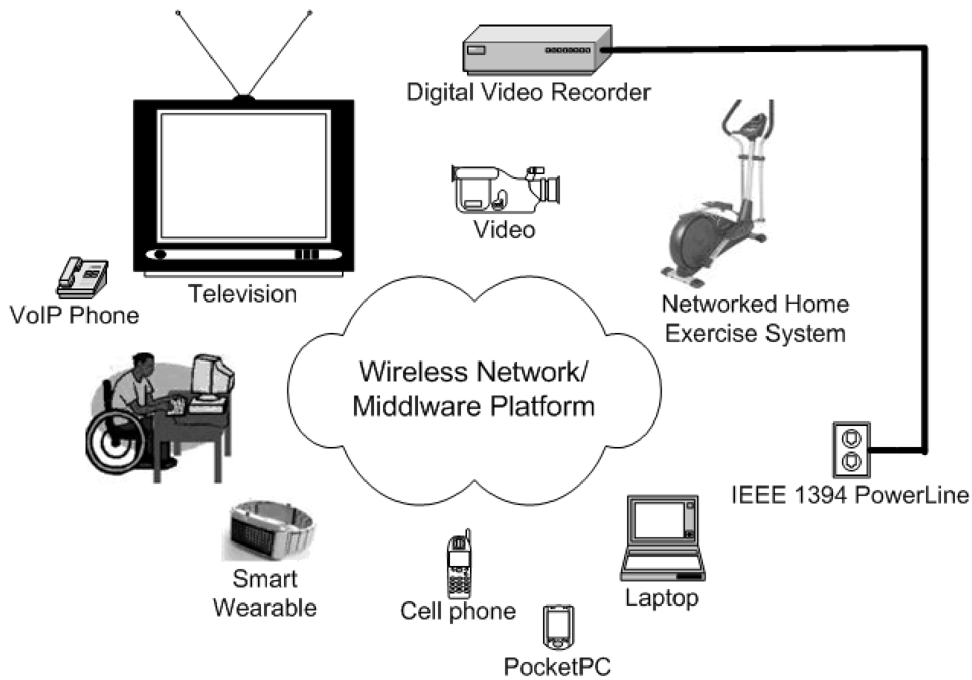

Figure 3. Conceptual model of a ubiquitous home environment. The intelligent appliances and other computer entities can interact through the home network.

3.4.1 Emerging Smart Wearable Healthcare Technologies

Today, smart wearable devices are under development to cover the specific needs of several groups of end-users (or consumers), e.g., home telemonitoring for chronic patients, blood composition monitoring and drug delivery for diabetic patients, early disease prevention, telemonitoring for cardiovascular and pulmonary diseases.

Smart health wearable devices may be attached to clothes, jewelry or wristwatches; or they may be separately wearable (e.g., a chest belt heart-rate monitor). Generally, a smart wearable personal system should be light in weight and have low power consumption, reasonably low in cost, easily accessible by an inexperienced user and able to maintain a network connection [29].

One of the most critical decisions to be made, in early stage of the development, concerns the scenarios of use and consequently the operation modes and embedded alerting algorithms to be developed. Several major issues that have to be addressed in order to satisfy user needs and implemented within the development and validation phase of smart health wearable applications are:

- ***Telecommunication:*** the link between sensors or link between smart wearable device and healthcare provider (or through intermediate wireless telecom facility (e.g., mobile phone).
- ***Data storage:*** a backup data buffer solution is usually necessary, especially because networks are not always available.
- ***Human technology interface:*** includes the graphical user interface, speech interface, tactile interface and so on.

- ***Patient safety:*** relating to potential risks from any electronic or radiation device (e.g., electromagnetic fields).
- ***Standardization and interoperability:*** smart wearable devices are being developed in a way that precludes communication between them and clinical information systems, which is undesirable. Structured but open communication standards and messaging protocols would bring subsequent clinical, administrative and research benefits.
- ***Biomedical sensors:*** A new generation of biomedical sensors is emerging that could generate new approaches for timely diagnosis, ambulatory healthcare, care at home and at the point of need. These include wearable non-invasive sensors that can be applied in contact with or near to the body (e.g., wristwatch, belt) and measure an impressive number of physiologic signals (e.g., ECG, pulse, blood oxygen saturation, respiration, skin temperature, blood pressure, C02) and activity and movement signals (e.g., EMG, posture, fall, movement, speed, acceleration and contact pressure). Wearable devices benefit today from significant progress in system integration and miniaturization and can be applied in different body locations.

3.4.2 Gaming & Home Exercise

The U.S. gaming industry has continued to grow dramatically over the past decade, with an estimate of $13 billion in sales in 2002 [30]. Along with the rapid progress in E&IT, the gaming industry has also involved a suite of novel technologies:

- ***Virtual Reality*** has been intensively integrated into the gaming technologies. 3D computer graphics, computer music and tactile interfaces have been intensively used in enriching the sensation of computer game users. Ironically, this kind of “augmentative interface” idea was originally developed by the rehabilitation community to provide alternative interfaces for disabled users.
- ***Wireless access:*** Most gaming platforms nowadays can be used as stand-alone computing entities, for example, the latest Xbox platform (Xbox 360) by Microsoft uses three custom IBM PowerPC-based processors with wireless support, and can interact with other home appliances (e.g., central storage, media player) in the home network [31]. These gaming platforms with wireless access capability would ideally fit into the ubiquitous home environment.
- ***Online games:*** A lot of computer game software today is also network accessible: computer game users can log in to internet game servers and either compete against or collaborate with some other user. Online games have become one of the fastest growing segments in the international entertainment industry. For example, popular online games in South Korea are enjoying a four million-strong subscription base [32]. This popularity indicates that gaming technology could be used to motivate the users’ participation in rehabilitative therapy.
- ***Standard interactive ports:*** Force feedback devices such as joystick, wheel, mouse and so on have been widely used in computer games. All together, more than 500 games use force feedback and more than 100 tactile hardware products are available on the gaming market [33]. Using scientific insights from the robotic therapy field, the authors’ group is developing a framework to use force feedback devices in rehabilitation. Although the mechanical power of force feedback devices is limited, it has proven to be effective at providing assistance to hemiplegic patients in initial pilot studies. In addition, the commercial device could easily be approved by regulations (e.g., FDA) as rehabilitation equipment that could be safely used in the home environment [34].

Considering its high availability, low cost and associated large and motivated user populations with existing accessible communication technology and standards, gaming technology can readily be used as a tool for home rehabilitation, especially using approaches such as Computer-Assisted Motivated Rehabilitation (CAMR), since research shows that therapy that proactively considers motivation is more likely to be effective in functional restoration. [35]

3.4.3 Home Information Infrastructure: Networking and Middleware Platform

An inherent property for wearable sensors is their mobility. Hence, optimally, they should be able to communicate their measurement data wirelessly. Different technical solutions based on network standards (e.g., WiFi or IEEE 802.11 local area network, Bluetooth personal area network, and infrared) have been introduced. In general, there is a tradeoff between these options.

Middleware for home healthcare systems comprises both hardware and software—its aim is to provide a platform to which the sensors send their measurement data, and to send control data to actuators, and where the data is processed further, stored, and presented, or from which the data are further transmitted for central storage. As home networking – and more generically, ubiquitous computing environments – are emerging, in order to be affordable and cost-efficient, health monitoring systems would also need to support generic platforms (i.e., to interoperate or coexist with other platforms), such as home automation platforms. This is especially true for middleware, networking technology, and user interface devices used for user feedback.

Potentially integrated into this mix are the IEEE 1073 standards, also called Medical Information Bus (MIB), which provide "interconnection and interoperability of medical devices and computerized healthcare information systems" [36]. As shown in Table 1, MIB standards consist of a family of substandards organized in an object-oriented framework. MIB defines nearly all of the elements (e.g., information model, communication model, service access) needed to implement wearable monitoring systems. In the MIB model, this section of the chapter maps to the bottom three layers; more information about the P1073.1 layer is given in Section 3.4.4.

P1073.1 provides definitions for information representation and interchange.
P1073.2 defines the application profiles which specify protocols and services relevant to the upper three layers of the ISO/OSI reference model.
P1073.3 specifies protocols and services for connection and message transport, using existing international standards where possible.
P1073.4 addresses the cable-connected physical layer.

Table 1. Family of MIB Standards in Object-Oriented Framework [IEEE 1073 Website]

As an example of a home healthcare middleware platform solution, the home environment is generally equipped with a server (e.g., a home server) and a local area network, to which the wearable sensors/actuators may discover/control and send data using different network protocols (e.g., Wireless LAN (WLAN), Bluetooth, X-10, Power lines, infrared). The technology and software issues for health monitoring and other intelligent applications based on an ad hoc LAN concept are being explored in many network communication protocols, including Universal Plug&Play (UPnP), Open Service Gateway initiative (OSGi), Jini (Java/Jini), etc. In these concepts, wearable health-monitoring sensors may be considered as ad hoc networked (mobile) devices, each providing a service to the network (e.g., access to health data). A healthcare application residing in the network (e.g., running on a home or remote server) receives the data from the sensor and sends the command to the actuator dynamically and takes the necessary actions such as storing, processing, alarming, and giving feedback. The framework provides support for dynamic updates of the sensor and actuator or other software or intelligent agent as well as management of their mobility (e.g., discovery, control, communication).

3.4.4 Infrastructure for Personalized Interface: Universal Remote Console (URC) Standard and Related Technologies

The vision of ubiquitous computing as "user-friendly computing resources anywhere and anytime" where services and devices "disappear" into the environment has already emerged. As discussed in above sections, network and middleware technologies are available in the home enviroment, providing methods for seamless discovery, controlling and eventing. However, user interfaces of networked devices and services still must be authored separately for each controller platform. Furthermore, many existing user interfaces are not intuitive and natural for human users; a *personalized interface* needs to be regenerated based on the individual's personal preference and capability.

A standardized but flexible abstract user interface description for target devices (e.g., intelligent appliance) or services (e.g., Web services, software program) will be required, so that any remote control can connect to discover, access and control a remote device or service on top of a network communication protocol (e.g., UPnP, Java/Jini, OSGi). With such an abstract user interface description, a remote control with universal interface capabilities (e.g., speech interface, natural language interface, tactitle interface) should be able to be supported by various computing devices, ranging from desktop computer to HandheldPCs and so on.

Among many of these efforts to develop a scheme for automatically generating a user interface on a remote control [37, 38], the V2 committee within INCITS and under ANSI has developed Universal Remote Console (URC) standards for the discovery, selection, operation, and substitution of user interfaces and options [39]. The purpose of V2's URC standard, which has become an official national standard (ANSI/INCITS 389-393-2005) and is under consideration to become international standard ISO/IEC 24752, is to facilitate the development and deployment of a wide variety of devices (from different manufacturers) that can act as URC's for an equally varied range of devices and services (see also Chapter pt2_Danturthi).

As shown in Figure 4, the URC standards specify communications between a target device or service that a user selects to access and operate and a Universal Remote Console (URC) that presents the user with a remote user interface through which they can discover, select, access and operate the target. The URC is software that is typically hosted on the user's physical device, but a distributed approach is also possible. Communications between the target and URC take place over a network, the target-URC Network (TUN). Interaction between a target and a URC consists of a discovery phase and an optional control phase. The discovery phase initializes the URC to locate and identify all available targets and their sockets. The control phase is the time period during which a target and a URC initiate, maintain and terminate a control session. A control session is a connection between the URC and a target's socket for the purpose of the URC controlling a functional unit of the target. The user interface (UI) builder in URC will generate the user interface on URC with target information and supplemental resources on the URC, from the target, or from a remote network.

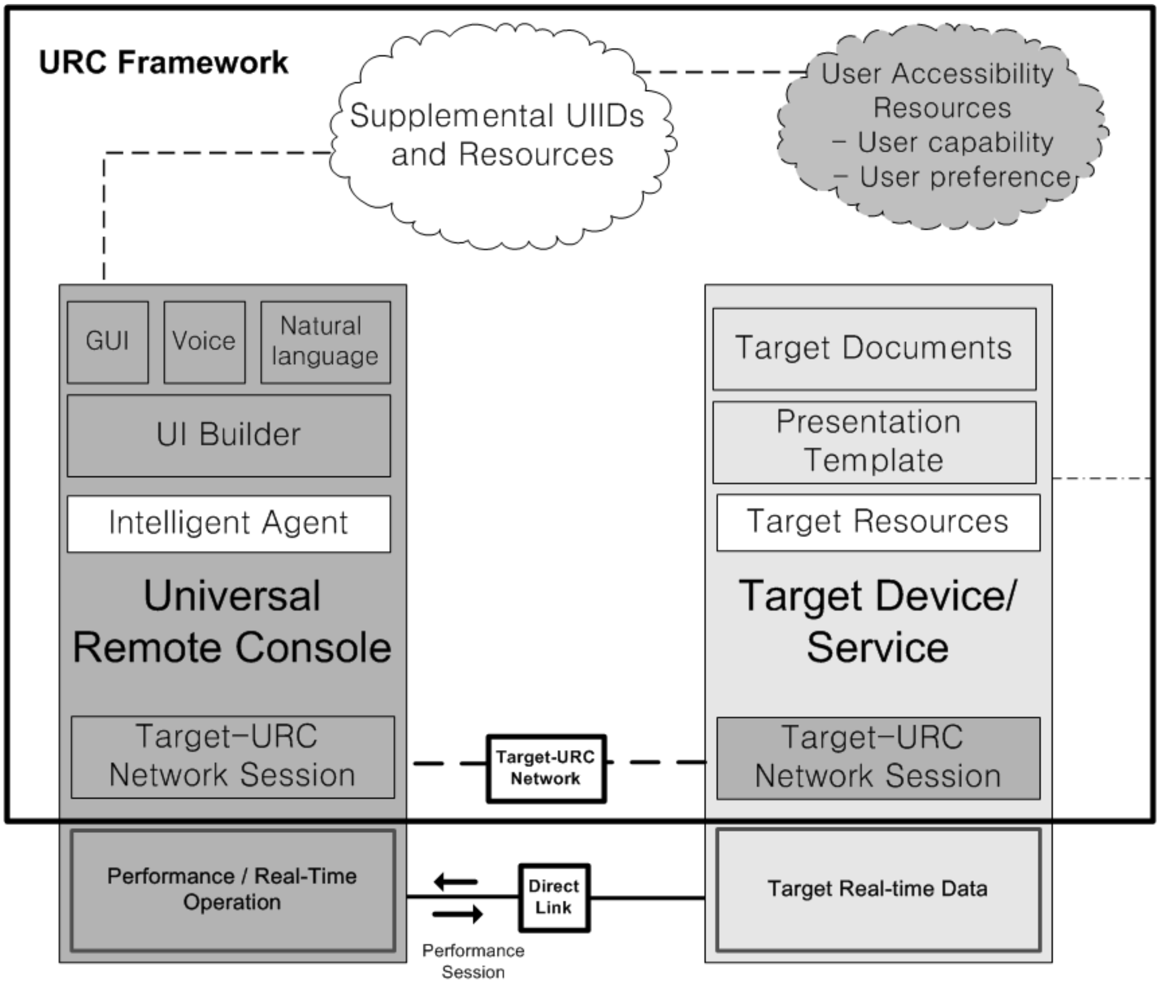

Fig. 4. URC Standards Overall Framework is described within the black frame; outside the framework is an optional performance session. The user interface (UI) builder in URC will generate the user interface on URC with target information (e.g., target document, presentation template, resources) and supplemental User Interface Implementation Description (UIID) and resources on the network, which is connected to URC by Resource URC Network (RUC); this process is optionally involved with an intelligent agent embeded in the URC. Besides TUN, a performance session may run on Direct Link, which is not necessarily compliant with V2 standards and transfers high frequency performance data between URC and the target.

So how can these emerging URC standards benefit home rehabilitation applications?

- ***Universal Interfaces:*** By using URC, which supports novel interfaces such as speech interface, natural language interface, tactile interface and so on, the user may use those interfaces to interact with a V2 target that may not support these features.

- ***Personalized Interface:*** One of the important resources URC can use to generate a user interface is User Accessibility Resources, which include both user capability and preference. Thus, a URC can always generate a personalized interface, for example, in the user's native language and a big font size for a non-English-speaking user with visual impairments.
- ***Device Independency:*** The URC standard provides a standard mechanism for products to share their functionality with remote controls. URC could range from desktop PC to PDA to cellphone. Thus it allows a manufacturer to support all of these and other options without having to create or even predict what the user would like.
- ***Intelligent Agent Programming:*** The URC standards allow the intelligent agent to be in the controller. The intelligent agent would allow the user to control home devices in many ways we cannot do today [40]. The Task Model Description (TMD) for an intelligent agent is one of the substandards that the INCITS V2 committee is working on today.

Along with three other RERCs, the RERC-AMI is a member of the INCITS V2 workgroup and is involved in multiple V2-URC activities. MedURC for medical devices (see also Chapter Pt2_Danturthi) and Interfaces for UniTherapy technology for rehabilitative assessment and therapy (see Section 4, below) are two prototype projects developed by the authors' group; the group is also proposing an accessibility schema to set up a user accessibility profile that URC can use to create a personalized user interface (as a master's thesis project). An outgrowth of this work is MUPad software tool, which was designed to provide a graphical user interface for generating V2-URC compliant XML documents. This assists a developer in generating V2-URC compliant files for a target device or service without requiring much previous knowledge of the V2-URC standards (e.g., schema, grammar).

4. UNITHERAPY TECHNOLOGY AS A PERSONALIZED HOME REHABILITATION APPLIANCE

As discussed above, there is great potential for home rehabilitation when an appropriate support system (both interpersonal and technical) is available. This section presents the development and implementation of a consumer-centered alternative therapeutic strategy for neurorehabilitative therapy: a *personalized home rehabilitation framework*, called UniTherapy, that supports a rich menu of diverse forms of therapy and assessment, adapted for the home environment.

4.1 CONCEPTUAL MODEL

The design of such a personalized rehabilitation framework starts with understanding the user needs, roles and interactive sequences of each user involved in the rehabilitation process. Three roles are defined: *Therapy Designer*, *Telepractitioner*, and *Home User*; more roles can be defined in finer granularity. The Therapy Designer has full access to UniTherapy's design suite to create personalized intervention protocols for the Home User (patient) and optionally the Telepractitioner, with the protocol able to be refined based on the outcome of timely assessment of the patient's recent progress. All the tasks in protocols can be put into two categories: self-routine tasks, which a Home User can run by himself; and interactive tasks, where a Telepractitioner will supervise and periodically interact with the Home User remotely, and evaluate results, with the ability to remotely change the intervention protocol, which depends on the protocol's setting. A Home User participates in all aspects of intervention sessions, and optionally can access his or her own progress and history - positive feedback may improve their motivation. A Home User doesn't need to design intervention protocols, although she can design goal-directed tasks herself as part of an intervention. These *roles* may change over the stages of an iterative rehabilitative process (e.g., a practitioner may assume both Therapy Designer and Telepractitioner roles).

4.2 THERAPEUTIC DEVICES

One requirement for the home rehabilitation framework is that it have support for mass-marketed devices that can be used in computer-based therapy and assessment. By supporting the DirectX standard [41], potentially all input devices compliant with the Microsoft Windows/DirectX platform can be used within the UniTherapy framework. For instance, UniTherapy supports force-feedback joysticks, force-feedback driving wheels, various pointing devices (e.g., mouse, trackball, PDA stylus pen) and Windows keyboards. Some features in UniTherapy, though, are only relevant when using force-feedback devices. UniTherapy also supports customized devices that are compliant with the DirectX standard. For example, the authors' group also has designed a larger, customized joystick device called TheraJoy [42], which is applicable to vertical as well as horizontal arm movements that include the shoulder. UniTherapy also is supporting customized assessment and therapy capabilities for the TheraDrive wheel project [43]. UniTherapy can program a series of force effects such as constant, spring, damper, and inertia on the Joystick via Microsoft DirectX Software Development Kit (SDK). Signal translation is implemented between several types of devices, for example, a utility called "JoyMouse" implemented in UniTherapy can capture a joystick's signal and use it to control the mouse cursor. This provides an accessible way to use a joystick to perform windows goal-directed assessment tasks which are only open to mouse.

4.3 ASSESSMENT, THERAPY AND TELEREHABILITATION SUPPORT

Assessment is a critical component of the framework, important both for evaluations of performance so as to support an iterative optimization process and as a key motivational tool. Assessment tasks include four toolboxes: Range of Motion (ROM), Tracking, System Identification and Conventional Forms.

- ***Working in User Ability Space:*** Range of motion (ROM) maps between the workspace range and the user capability range. This mapping is based on a 2-step ROM task that is normally performed upon first use and prompts the patient to draw a circle as big as they can. UniTherapy then fits the data with a rectangle that is used to represent the patient's estimated ROM. This mapping helps ensure that the user can reach most of the space used for subsequent tasks.
- ***Tracking*** has already been widely used in the practice of Neurorehabilitation, with the purpose being to assess various aspects of a person's movement capability. UniTherapy supports two categories of tracking tasks: discrete tracking (point-to-point target acquisition) and continuous tracking (pursuit/preview tracking), with different instructions to the patient.
- ***System Identification*** enables the Therapy Designer to design a task that applies predefined force perturbations to the subject and measures their response while under a certain instruction (e.g., "hold," "relax"). UniTherapy records force data and instruction as input, and the subject's movement data as output.
- ***Conventional Forms***: This toolbox currently includes eight questionnaires instruments (e.g., Barthel Index [44]), which are integrated into UniTherapy as form-based assessment instruments.

Movement data (e.g., position, timestamp, applied force) are recorded into XML files for later analysis, with the data structure defined by an XML schema. A data analysis module is being developed. Results can be not only displayed in both graphics and report form, but also stored as an XML file with the data structure that is described by an XML schema. The core suite of assessment metrics such as movement time, reaction time and path error are retrieved intelligently once the data are input into the program, based on input device type (e.g., joystick, wheel), and task type (e.g., discrete tracking, continuous tracking, system identification).

UniTherapy supports the integration of third-party computer game programs by treating them as add-ins and setting up shortcuts. Therapy Manager in UniTherapy allows the user to add/remove third-party programs and change sequences. A collection of simple arcade games (e.g., smart driver, Pong, Pacman), are current examples of fun motivation therapy tools where UniTherapy can run in the background. UniTherapy can get access through DirectX to sampling joystick port signals without affecting the performance of most games.

A Telerehabilitation Link between patient interface (PI) and telepractitioner interface (TI), which is supported by TCP/IP network, has been implemented. Both the PI and TI support a view of the patient's performance data in real-time. The result can be viewed at both sides in graph and report forms afterwards. As an option, the user at the TI can decide if the patient can participate in the task design phase. Instant messaging (IM) and computer-based teleconferencing is integrated into UniTherapy so that both users at the PI and TI can communicate by audio, video and text.

4.4 USABILITY & ACCESSIBILITY DESIGN: HOME REHAB APPLIANCE AND URC STANDARD-RELATED TECHNOLOGIES

The Home User version of UniTherapy is designed and implemented as a multi-modal application with a simple user interface that resembles a media player. As shown in Figure 5, a Home User can load the protocol predefined by their Therapy Designer into UniTherapy as they would load a CD into CD player; the descriptive information such as "protocol title," "task information" and "status" will display information for the Home User in a manner that appears simple and intuitive to use. By using the existing telerehabilitation link telepractitioners or caregivers can supervise the Home User in real-time. The authors are also investigating integrating user-agent technology into UniTherapy to provide context-awareness help online (e.g., an animated character could provide some simple positive feedback (e.g., "good job!") to the Home User after the goal-directed task is finished).

The Home User version is also compliant with the V2-URC standards. The authors' approach is to treat UniTherapy as a *target service*, called *home rehab appliance*, and thus provide abstract user interface information in V2-compliant documents, which are sufficient for a URC to construct a full-function custom-tailored user interface for UniTherapy on the remote control. A URC prototype running on the PocketPC is implemented and can successfully operate UniTherapy as a remote control; the authors are using the TUN library developed by the Wireless RERC, which is implemented on top of UPnP Remote UI standard, and are gradually adding universal interface support into the URC. An intelligent context-aware UI builder with user capability and preference support is also under development. A critical part of this process is having the user complete a short survey on user accessibility and preferences. UniTherapy's own assessment tools can be used to augment information on a user's performance capabilities.

Finally, the authors are developing a generic UPnP control point, which will be embedded into the UniTherapy home user version so that UniTherapy would evolve into an Environmental Control Unit (ECU) for UPnP-compliant home appliances within the home environment.

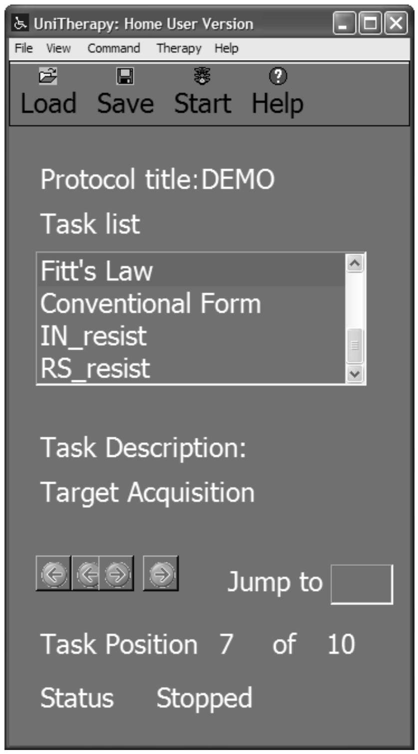

FIG. 5. UniTherapy home user version: designed as a home rehab appliance resembling a CD-player user interface. A user can navigate through the protocol list and select the task; simple voice commands (e.g., “start,” “stop,” “next,” “previous,” “repeat”) are supported, which is implemented using Microsoft Speech SDK; thus the home user can operate via voice command. Certain accessibility features are implemented and are ready to be used for screen-reader application, with more planned, based on usability evaluation.

In summary, an interactive framework for a personalized home rehabilitation appliance has been implemented with a consumer-centered design and CAMR approach. A diverse menu of assessment capabilities are available, and can be used together with other services that include a protocol manager and data analysis tool with a telerehabilitation link. UniTherapy has been used as a research platform for rehabilitation and usability studies in 3 sites in the Milwaukee local area [42, 45, 46]; and the authors received positive user feedback from patients and therapists during initial usability research studies.

5. FUTURE DIRECTIONS

To implement the personalized home rehabilitation model discussed above, there is still a lot of work to do. A few key tasks are:

- Additional research and clinical studies, which quantity the outcome of personalized intervention in home rehabilitation, need to test the hypothesis that personalized interventions will optimize the outcome of rehabilitation. The authors are planning to conduct a new research study that will deploy the UniTherapy platform at patients' home sites with telerehabilitation link support, with the hope that the result will provide hard evidence to support the personalized home rehabilitation approach.

- Web service has evolved into a dominant distributing computing model; thinking about healthcare as a service, this brings us new opportunities to collaborate with experts in different aspects of rehabilitation (e.g., physical therapist, rehabilitation engineer) to set up an optimized model that is better tailored to an individual.
- New opportunities and issues are emerging around the V2-URC standard. For example, the authors' group is looking into creating an accessibility profile for identifying an individual's capabilities and preferences. Another important example is the V2 workgroup's emerging Task Model Description, which can be used to build a task model that can be used to control one or more targets or services. The authors are especially interested in how to generate a personalized healthcare interface that establishes leadership of solutions for accessibility, and in how the home healthcare devices could interact with a ubiquitous home environment.

In summary, despite some restrictions, personalized healthcare systems are emerging [47, 48]. The authors are developing a universal access platform for personalized home rehabilitation with support by telerehabilitation link; the authors' hope is that in the next few years, an intelligent, personalized rehabilitation appliance will be implemented in the home environment and provide an alternative consumer-centered approach for rehabilitation that has the convenience of home, and provide access to a much larger population who could benefit from transfer of this scientific research.

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