SCRIPT: Tele-robotics at Home
Functional Architecture and Clinical Application

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Abstract: After the event of a stroke, patients have at least 12 months during which their brains are highly susceptible to the benefits of neuro-rehabilitation treatments. On the other hand, due to the high costs of clinical neuro-rehabilitation, post-stroke treatments are limited in all countries to only a few weeks after the stroke event. Hence, any system aimed at prolonging neuro-rehabilitation at patients' homes, and with low-cost treatments, addresses a major issue in the current health management systems. Recent developments have revealed a great potential for robotic devices delivering repetitive training to improve arm function after stroke, thus facilitating a high intensity and a large number of repetitive training. The SCRIPT project aims to develop robotic technologies for the home as it would enable self-administration of more intense and more frequent exercises, by enabling hand and wrist exercise that have great potential for contribution to personal independence. Remote management and support of the patient is incorporated through a communication platform that supports the remote adjustment of the therapy program. In this way, the patient can exercise at home, while the exercise is remotely supervised without increasing therapist time, while reducing the frequency of hospital or clinics visits.

1 INTRODUCTION

Functional recovery from stroke demands a long period of physical and often cognitive rehabilitation. Research into motor relearning and cortical reorganization after stroke has provided a neurophysiological basis for key aspects that stimulate restoration of arm function (Schaechter, 2004; Krakauer, 2005). These key aspects include high training intensity, active initiation and execution of movements, and application of functional exercises. Technological innovations provided an opportunity to design interventions that take many key aspects for stimulation of motor relearning into account, of which rehabilitation robotics is a well-known example. With such a device, the required amount of movement support can be provided, thereby allowing active practice when this is not possible otherwise. This increases the potential to train intensively, with the patient's active contribution to functional exercises.

The application of rehabilitation robotics has been shown to be effective for the hemiparetic arm (Prange, 2006; Kwakkel 2008; Mehrholz 2008). However, transfer of robotic training effects to activities in daily life is limited, as is observed for most interventions in stroke rehabilitation, including conventional therapy (Wagenaar, 1991). Contemporary robot-aided therapy focuses mainly on the proximal arm, and results in improvements in the proximal arm only, without generalization to the wrist and hand (Prange, 2006). This is while wrist and hand play a major role in a person's functional independence. In order to maximize independent use of the upper extremity in daily life, it is important to include functional practice of the wrist and hand.

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In the setting of the rehabilitation centre, intensive training of arm and hand is supervised by highly skilled professionals. However, the time that can be spent on training in such intramural settings is limited. Due to the high costs of clinical neuro-rehabilitation, post-stroke treatments are limited to only a few weeks with limited treatment resources after the stroke event in many countries. Hence, any system aimed at prolonging neuro-rehabilitation out of the clinics, i.e. at patients' homes and with low-cost treatments, addresses a major issue in the current health management systems.

While there is growing evidence that rehabilitation technologies are beneficial to the patients' recovery of functional and motor outcome (i.e., Prange, 2006; Kwakkel, 2008; Mehrholz, 2008), the uptake of these technologies has been slow. This is thought to be caused by the lack of stronger clinical evidence for usefulness, adherence of carers/clinicians, lack of platforms designed along clinically useful practice, limitations on post-discharge practice frequency based on service or motivation limits, absence of platform flexibility, cost and weakness in addressing interoperability issues among healthcare systems in the EU.

The SCRIPT (Supervised Care & Rehabilitation Involving Personal Tele-robotics) project aims to address several of these important issues: using robotic technologies at home as it would enable self-administration of more intense and more frequent exercise, by enabling hand and wrist exercise that have great potential for contribution to personal independence. This is the concept of telerehabilitation considered by many as the future (Hermens, 2008).

However, telerehabilitation is still in its infancy. In a recent review (Johansson, 2010), only very limited amount of ICT-supported treatments were available. Of the nine studies included in the review, four studies focused on a teleconsultation service for stroke patients. With respect to technology-supported telerehabilitation, only three studies were found: two utilizing the same virtual reality-based system that provided motor tasks to the patients and only one study, originating from the European HCad and HelloDoc projects, utilising a sensitized exercise table with synchronous video teleconsultation to enable supervised arm/hand exercising at home. One of the aspects reflecting the present immaturity of telerehabilitation concerns the unavailability of a decision support system. In order to make large scale clinical application possible and to make such systems cost-effective, it is required that a decision support system is in place that supports clinical decision making by doing a smart analysis of the physiological and biomechanical data in its proper context.

The aim of the present paper is to present the functional architecture and future clinical directions of the SCRIPT tele-robotics platform, which is targeted at improving arm function after stroke by enabling home-based, robot-supported arm and hand training. Since designing such an interactive system often doesn't meet the criteria needed for a usable system, user-centred design methods are applied from the start of the development of the interactive system (Abras, 2004). By applying four steps: identifying needs and user requirements, developing alternative designs, building interactive versions, evaluating the different options (Sharp, 2006), the end user is allowed to shape the design of the SCRIPT tele-robotics system.

2 FUNCTIONAL ARCHITECTURE

The SCRIPT project will create a system, progressing beyond the present state of art, in a number of aspects. The goal of developing a home usable device for chronic stroke patient poses many challenges. At its heart, safety during robotic interaction is an elemental consideration. Passive-actuation is chosen due to its superior and inherent safety and importantly, its implications on reducing cost. In addition, there is evidence that passive-actuation can be as beneficial as active actuation (Amirabdollahian, 2007). Therapeutic scenarios detailed in user-driven design framework are to be implemented in the prototype devices as meaningful human-robot interaction. The idea is to identify and tune, based on person's capabilities, the percent contribution required by the robot during human-robot interaction. Figure 1 shows the functional blocks of the complete system.

The project considers two different user interfaces for the interaction with the system: one for the patient and one for the clinician. The user interface for patients provides motivational and engaging content with an easy to use front end (which supports multiple languages for interaction). Patients' therapy is facilitated using a series of therapeutic games. In addition the system will allow on-line support, assessment of instructional videos and user friendly and motivating monitoring functions of the progress made.

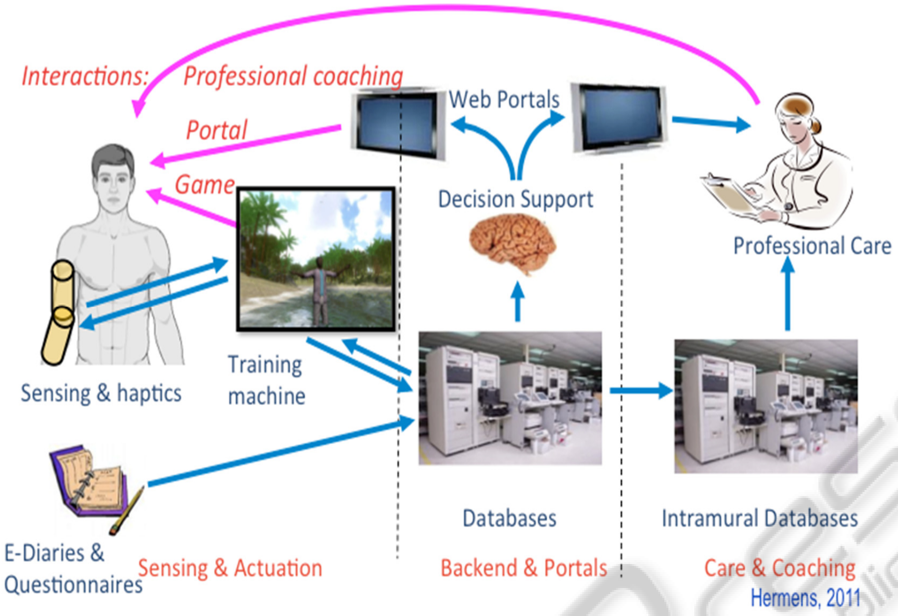

Figure 1: Functional architecture of SCRIPT system.

The user interface used by the clinicians will include different features, required to remotely manage or observe, and in the case of active device provides a chance for remote tuning of the device. Clinical users require to observe progress in a range of different aspects but not necessarily using the same progress indicators as seen by the patients.

Automated data collection will be supported on the outcome variables of the exercises, subjective data from questionnaires and diaries and intermediate process variables for treatment. These functions will be performed in a secure dependable way, taking care that privacy and data integrity are guaranteed. The training equipment generates large quantities of data that cannot be monitored continuously by the health care professional or by the patient. A set of clinically relevant features will be determined continuously and made available to both the clinician and the patient. These will be combined with contextual information and reasoning, to result in a set of recommendations and a comprehensive presentation of the most relevant data.

2.1 Building Blocks

Considering the functional architecture of the SCRIPT tele-robotics system, figure 2 displays its building blocks. A short description of its main components is presented below.

2.1.1 Robotic Device

The device consists of a commercially available weight support mechanism (Saebo Mobile Arm Support) on top of which a wrist and hand therapy device is mounted. The device can be used for all activities of daily living. The wrist and hand component includes manipulation of wrist flexion/extension and different grasping movements with the thumb, fingers and palm of the hand. Assist-as-needed is provided through passive and active actuators, respectively springs and electric motors. Combining passive with active actuators provides an optimal balance between power output, control opportunities and device weight. The actuators and mounted sensors also allow for interactive feedback and haptic object manipulation.

2.1.2 Adaptive Therapeutic Human-robot-interaction

Therapeutic scenarios detailed in user-driven design framework are to be implemented in the prototype devices as meaningful human-robot interaction. To do this, this block focuses on position lag and energy transfer direction (from human to robot or vice versa) towards benchmarking/guiding the interaction between the person and the robot prototype. The idea is to identify and tune, based on person's capabilities, the percent contribution required by the robot during human-robot interaction. The under-lying interaction is compared to established models

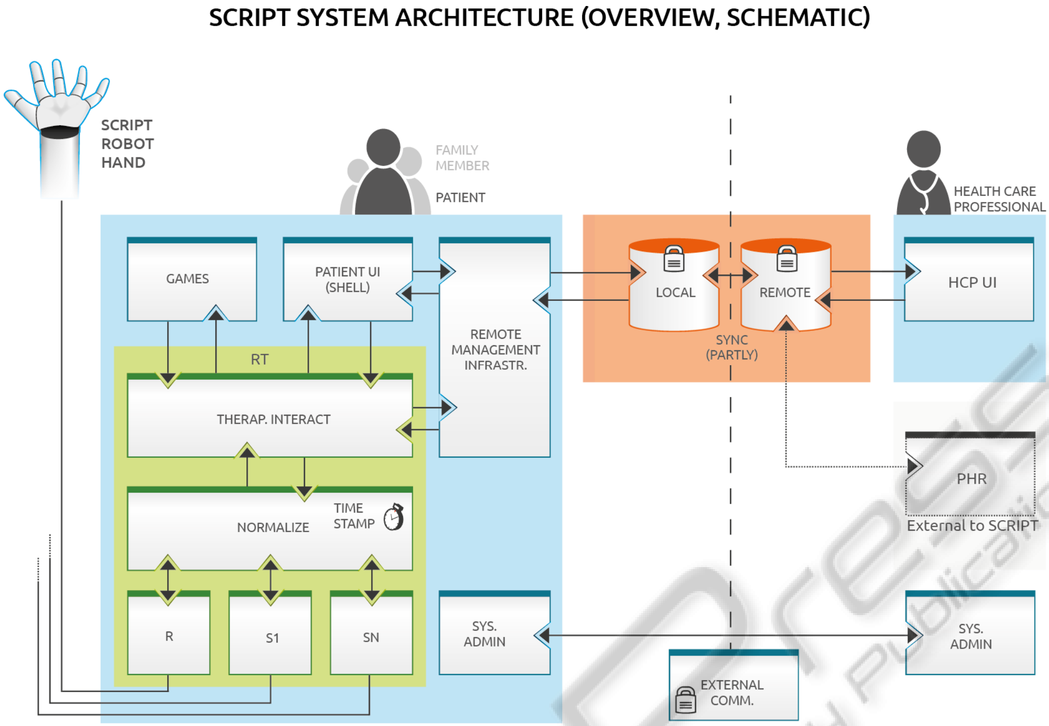

Figure 2: Building blocks of SCRIPT system.

such as minimum jerk (Hogan, 1984) providing opportunities for new benchmarks for grasping. Using these benchmarks, it is possible to adjust the robot's assistive or resistive forces automatically providing an adaptive and therapeutic human-robot interface.

2.1.3 Remote Interaction and Decision Support

The sensor signals from the robotic device, reflecting the human interaction during the game, are sampled, processed and normalised to enable real-time comparison with the pre-determined therapeutic goals. A subset of the central database is loaded in the local database at start-up, containing patient history and specific game settings. During the use of the SCRIPT system, new data is added to the local database continuously and synchronised with the main remote database. The data is also used to generate reports to be included in the patient health record.

A model will be developed that is able to automatically process the sensor data in different consecutive steps to obtain a set of dynamically changing features. These will be combined with contextual information and reasoning will result in a set of recommendations and a comprehensive presentation of the most relevant data.

2.1.4 User Interfaces

Portals will be developed that enable a comprehensive and motivating presentation of the data. This requires a very different presentation for the patient and the clinician that coaches. Whereas clinicians are used to interpreting graphs, this is often not the case for the patient, so starting from the user requirements (from the patient perspective) special GUI's have to be researched and developed.

In this way the loop will be closed at three different levels, enabling adequate and efficient monitoring and coaching: the patient gets direct feedback during the exercise from the robotic device, he is able to monitor his improvements via the portal and he receives coaching from his care professional, who is also able to monitor the progress via the portal.

3 CLINICAL APPLICATION

3.1 Clinical Evaluation

The clinical study design applied in this project involves two different types of evaluation, underpinning technology development: Formative Evaluation (FE) or user-engagement in design and system development and Summative Evaluation (SE) or the evaluation of the finished (functioning) product.

In Formative Evaluations, users of a technology system can provide useful information during the process of system development (Monk, 1993). Initial engagement with the potential users of the system is needed to create a clear understanding of the target users and the context in which the users intend to use the system. In the process of specification the system is designed, developed and tested through an iterative cycle in which the developers are able to find out how easy/difficult the system is to use by users and to help them understand what problems the system poses and how these problems could be improved. The outcome of evaluation is considered and alterations made to the design for the next iteration of the prototype. This set-up of formative evaluations allows use and acceptance of the developed systems to be evaluated in practical situations.

The summative evaluation allows for assessing whether use of self-administered tele-robotic devices can influence improvement of arm and hand function captured during home therapy. This is made possible by recruiting volunteering patients at the chronic stage of stroke recovery, and allowing them to use the system at their comfort for a six-week period. Patients are assessed clinically; prior to, after and at two-month post-intervention using established and validated clinical outcomes. This investigation also allows validating usefulness due to involvement of three user-evaluation centres (University of Sheffield in the United Kingdom, San Raffaele S.p.A. in Italy, Roessingh Research and Development in the Netherlands) for each stage of the evaluation. Analysis of the clinical outcomes, as well as amount of use, intensity of training, usability and user acceptance, allows for a comprehensive analysis of the factors contributing to improved arm and hand function and compliance to home-based treatment.

At present, the SCRIPT project is in its initial stages. The stage of user and system requirements identification during FE is ongoing. In the next stages of the project, these requirements will be implemented during design of the SCRIPT system, after which SE will be carried out.

3.2 Future Clinical Directions

The SCRIPT tele-robotic platform ultimately enables application of robotic technologies at home. This allows self-administration of more intense and more frequent exercise, by enabling hand and wrist exercise that have great potential for contribution to personal independence. This is done by providing an educational, motivational and engaging interaction, which makes a therapy session more enjoyable while having the capabilities to provide feedback to patients (in support of relearning) and to the healthcare professionals. To enable this, remote management and support of the patient is implemented, through a communication platform that supports the remote adjustment of the therapy program, thus reducing the frequency of hospital or home visits. This is facilitated by incorporating clinical workflows into user interfaces used by patients and clinicians, while maintaining a customisable and easy to operate front-end for users. In this way, the patient can exercise at home, while the exercise is remotely supervised.

4 CONCLUSIONS

Based on a multidisciplinary approach, the SCRIPT tele-robotics system will be usable at stroke patients' homes after their discharge from the hospital, in order to improve personal independence. It provides immediate feedback on user performance using a decision support architecture. The feedback will be provided to both the patient and the health care professionals with in-depth considerations for security and confidentiality. The SCRIPT tele-robotics system will be beneficial to improve arm and hand function of stroke patients, while reducing hospital and home visits and having a large impact on reducing hospital costs.

During design and development, the system is adapted to user requirements. The project evolves from focus on user feedback during technology development (presently ongoing) and user acceptance during initial phases of try-out and testing, to analyses of added value and impact of such services applied at the patient's home, for additional important insight in contributing factors to success of home application.

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