Wearable Sensory Display to Facilitate Patient-Therapist Concordance in Knee Rehabilitation Exercises

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***Abstract*—Patients undergoing physical therapy have limited ways of assessing exercise correctness at home. Correspondingly, physical therapists lack visibility into their patients' rehabilitation processes when away from the clinic. Our approach to this problem is through a wearable electronic device that helps patients visualize the accuracy of their movements and helps therapists monitor the progress of their patients' home exercise programs. This feedback loop could facilitate recovery by helping patients and therapists collaborate on shared recovery goals.**

I. Introduction

Physiotherapy is an essential part of current treatment for patients recovering from an injury or suffering from musculoskeletal disorders (MSDs). Typically, it is a labor intensive process that requires patients to consult physical therapists for targeted exercises routines to recover mobility and strength. Treatment programs can last months to years requiring the patient to regularly visit the physical therapist to receive feedback on exercises and progress. Apart from the periodic visits, the patient must perform the exercises regularly at home; this aspect is critical to achieving rehabilitation goals. While the physical therapist monitors proper form and movement in the rehabilitation clinic, patients have little feedback on the correctness and extent of their movements when practicing at home. Moreover, the physical therapist has no way of checking correctness or compliance of the exercise regime in a home setting. Inevitably, the result of non-compliance or incorrect exercise form is a longer path to recovery for the patient and a heavier burden on the medical system.

Our research addresses this problem space for knee rehabilitation. Specifically, we focus on tracking exercise form, accuracy, and progress for the knee extension exercise and present the information in a holistic way to both the patient and the therapist. We accomplish this through a wearable computing device that utilizes an electroluminescent (EL) display as the feedback mechanism. In our solution, we do not directly address the problem of motivation, but rather focus on helping the patient visualize exercise form and provide the therapist with the ability to monitor the patient's home sessions. This feedback loop may lead to patient-therapist concordance, a term that describes a shared process where patient and therapist collaboratively make decisions about health goals. Compared to enforcing compliance, the concordance process is more successful for better treatment outcomes [1].

II. Background

While pervasive technologies are ideally suited to address the issue of supporting home exercise sessions, due to their ability to continuously track and communicate information, one can think of a simple paper based journal where the patient manually tracks exercise sessions. Diary solutions provide little feedback on exercise correctness and are prone to human error. However, diaries coupled with a mechanical device [2] that encourages proper movement would satisfy the design criteria for both exercise correctness and feedback. An unfavorable aspect of this system is that it requires considerable work on part of the user and relies solely on the patient to inform the physical therapist on their progress.

Indeed there has been considerable work in both commercial and research areas on automated bio-monitoring systems. In the commercial space, the bioPLUX Clinical System (plux.info) is a device that measures and displays muscular activity during rehabilitation sessions. While this device is compact and capable of transmitting data wirelessly, it is primarily designed for physical therapists as a medical device to be used in the clinic. With the advent of motion tracking peripherals in entertainment consoles such as the Nintendo Wii and Microsoft Xbox Kinect, researchers have designed applications that support rehabilitation from stroke [3] to helping patients recover their balance [4]. An undesirable aspect of these systems is that they require a substantial investment in expensive infrastructure requiring users to setup gaming consoles, peripherals and software.

In the healthcare research space, there has been abundant work into the use of wearable sensors to monitor therapy, with solutions that classify movement [5], analyze motion [6], and measure physical activity in specific populations [7]. However, most of these solutions have been biomedical in nature and have focused on particular technical aspects such as algorithms, or sensors. A number of studies have explored body sensor networks (BSNs) for both local [8] and remote physiotherapy treatments [9], but these systems require users to place invasive sensors throughout the body and are focused on communicating information to the therapist. While there has been work on interactive methods [10], [11], few have

PervasiveHealth 2012, May 21-24, San Diego, United States

DOI 10.4108/icst.pervasivehealth.2012.248754

combined the needs of both the therapist and patient. The most notable research, Thera-Network [12], is designed for patients recovering from various types of knee pain. This smart medical wearable device hastens the healing process by allowing therapists to remotely monitor rehabilitation exercises. The device however, is more focused on the issue of patient motivation and addresses the issue through an online social network.

While many of the approaches presented above are valuable and pertinent to our design, we explore the intersection of clinical practice and patient activities outside the clinic. Our goal is towards a wearable technology design that supports the process of concordance for physical rehabilitation where technology plays the role of a mediating artifact between therapist and patient. We focus on a user centered approach, considering the needs of both the patient and the therapist in the rehabilitation process.

III. Research Questions

Our research seeks to answer three interrelated research questions that will help us understand how to design and develop a wearable technology to support patients and therapists as part of a prescribed knee rehabilitation program. We ask:

- *How do we integrate the electronics and wearable enclosure seamlessly so it is easily usable?* Since we are creating a tangible user interface, we need to integrate electronics with wearable material so that it is compact and causes no discomfort to the user. From a patient-centric view, the wearable technology must be designed with the understanding that it is for patients who have limited range of motion. Ideally, the user should not be aware that electronics are embedded as part of the device.
- *What is the most effective way to visualize activity and progress?* The key challenge here is in designing a visual feedback interface that guides the patient on proper exercise form. How do we create intuitive visualizations that provides feedback on exercise repetitions, duration and success of correct movement?
- *How do we facilitate concordance between patient and therapist?* We acknowledge that this is a complex question, with social factors that our research might not be able to address. However, within the scope of our work, we can explore how technology can be designed to support and facilitate the process of concordance. Is creating a technology that provides added value to both the therapist and patient enough, or are there design considerations that can support this collaboration?

IV. User-centered Approach

We explore the research questions presented in the previous section from a user-centered perspective and introduce a design for a wearable device for the knee extension rehabilitation exercise. This exercise consists of raising the foot from a seated position and straightening the knee as much as possible and then lowering the leg slowly as far back as possible. A straight leg is at 0 degrees and a flexed knee is at about 140 degrees.

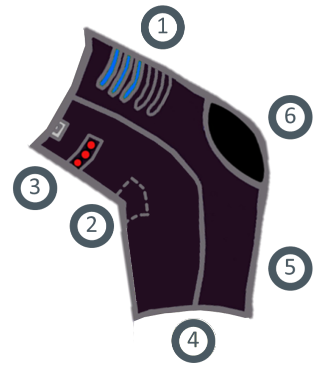

Fig. 1. Design of Wearable Prototype for Knee Rehabilitation

A. Overview of Design

A preliminary design of the wearable device with numbered elements is shown in Figure 1. Explanations for the numbered labels are given below:

1) The design employs strands of EL wire that serve as a visual display to the patient. The multiple strands provide constant feedback on range of motion and only light up when the exercise is performed accurately and correctly.
2) A flex sensor behind the knee measures the angle of the patient's knee extension. The sensor threshold can be adjusted by the therapist over time as the patient gains mobility. Thus, the EL wire will require progressively higher values to light up.
3) The buttons power the device and control various programming functions, such as starting and stopping the exercise session or initiating data transfer. The USB port above the buttons provides both patients and therapists the ability to wirelessly download exercise data onto a smart phone to monitor progress towards goals. This port also serves as a means to program the device (e.g., sensor threshold, required number of repetitions). To support the described functionality, a small Bluetooth module is attached to the USB port temporarily (due to power consumption constraints).
4) The bottom of the knee enclosure has a velcro opening running down the middle so it can be worn easily.
5) The front of the knee enclosure holds an Arduino based microcontroller for controlling the device and a lithium-ion battery for power.
6) A semi-rigid pad aids in aligning the device to the knee.

While the design presented above stores data from multiple exercise sessions, the EL wire display only provides immediate feedback for the current session. To help visualize data from multiple sessions an Android based application periodically downloads data from the device. This application provides a longitudinal visualization of exercise data to help patients reflect on their rehabilitation and aid therapists in monitoring patient progress over time.

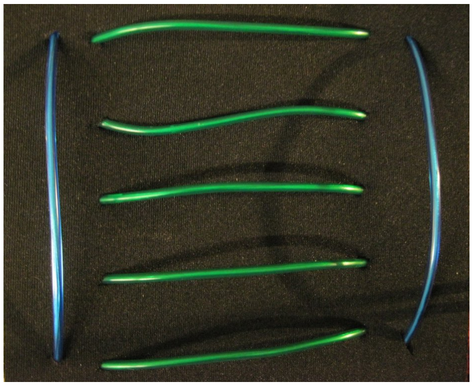

Fig. 2. EL Wire Display Mounted on Neoprene

Fig. 3. Over the Knee Test Harness

Fig. 4. Sleeve for Flex Sensor

B. Methods

Towards implementing the design presented in the previous section, we will employ an iterative process, consisting of smaller design-develop-evaluate cycles for the electronics, the wearable enclosure, and the smart phone application. In this cycle, we will consult with patients and physical therapists to better understand their needs and inform our design. Their feedback will help us refine our requirements for tracking knee movements and storing the data necessary to monitor a patient's long-term recovery. We will utilize a rapid prototyping approach to evaluate various component designs and materials. This summer, we will conduct a user study with patients consisting of semi-structured interviews and task based scenarios to evaluate the usability and performance of our fist prototype. The feedback from this study will inform further improvements to the design.

V. Preliminary Work

In our initial work we established that EL wire was ideally suited for wearable applications. Unlike, a traditional LED display, which requires separate connections for each LED and is somewhat rigid, a single one meter strand of EL wire can be weaved through clothing as a single piece. Moreover, it is low power, cool to the touch, lightweight and easily sewn into clothing. Much like LEDs, it comes in a variety of colors and the strands of wire can be easily spliced together. Figure 2 shows our current EL wire display which employs a bar graph (green strands) to represent range of motion. It is bordered by blue strands of EL wire which indicate that the device is powered and ready to use. These borders are also used to indicate completion by blinking when the patient has reached her exercise goals for the day.

We used an Arduino microcontroller programmed to gather the number of times the sensor flexed (exercise repetitions) and degree of flex (knee extension) through an analog input port to test the flex sensor. While we obtained somewhat consistent values simply by flexing the sensor with our fingers, we realized that it would function differently based on its position with respect to the knee. To test our hypothesis, we created two neoprene/spandex enclosures, one for over the knee (Figure 3) and the other for under the knee (not pictured but similar to the over the knee example). Each enclosure had a tiny sleeve to accommodate the flex sensor (Figure 4) to keep it positioned in a fixed location. When gathering data using the enclosures, we discovered that despite our efforts, the flex sensor gave us inconsistent values and had a tendency to bunch up regardless of where it was positioned. As a result, we are currently experimenting with circular knit stretch sensors [13], which have been successfully used in virtual reality gloves and suits. Our present work is aimed at solving these issues and iterating on our initial prototype to make it more compact and easy to use.

VI. Future Work

The main area for future work is in field-testing a functional prototype that supports performance of knee extension exercises at home. This involves refining the existing modules (knee enclosure, EL wire visual display, and electronics) and developing the Android application. Particularly, we need to focus on our EL wire display since it is the primary interface for helping patients visualize movement and form. In our current display, the patient has no way of knowing how far along they are in the session or how much longer they need to keep going.

The preliminary work presented in this paper has been primarily patient-centric and needs to address the requirements of physical therapists. Specifically, we need to work with therapists to extract metrics that they can use to evaluate patient progress, as well as create intuitive visualizations of exercise data. Possibilities include summary charts that plot performance data against weekly goals, and perhaps aggregating exercise data into an overall health rating for each patient.

Lastly, we need to evaluate if our wearable system facilitates patient-therapist concordance during the rehabilitation process. While it is hard to investigate concordance through compliance rates alone, a subsequent study could examine if interaction and collaboration increases when using our system as compared to a control group. If interaction between patient and therapist are higher while using our system, we could perhaps say that concordance is likely due to increased interaction.

VII. Contributions

The research presented in this paper lies at the crossroads of two approaches, a bio-monitoring clinical perspective and a patient-centric view of treatment. Our work has the potential to satisfy the needs of both physical therapists and patients by assisting therapists in tracking patients' progress and helping patients visualize proper movement and accuracy of rehabilitation exercises. More importantly, this research could lead to better patient-therapist communication by encouraging praticioner and patient to collaboratively decide on achievable goals for recovery. This could in turn help patients stay motivated [14]. Additionally, the use of this wearable rehabilitation device may also help therapists better understand how patients recover and the problems they face on the road to rehabilitation.

This work also brings together sensory displays from HCI to inform the design of a wearable health interface that can display, log, count, and transmit information to both patients and health care practitioners. Furthermore, we are extending research in wearable interfaces through a custom EL wire display that can be used by other researchers to communicate information intuitively. Lastly, we take a user centered approach to the design of physical therapy technology that views technology as an intermediary between patient and therapist that fosters successful health outcomes.

VIII. Questions for the Consortium

It would be extremely beneficial to examine the issues of concordance during the doctoral consortium. Particularly, are there other studies that have examined how technology can foster concordance in the health care system? Are there specific studies that examine patient-provider interactions and communications in health care? Moreover, are current medical practitioners prepared to deal with the challenges of working in partnership with their patients?

While we believe our research has the potential to foster concordance, what are the privacy implications? We assume that the patient wants to share her progress with the therapist, when in reality it may be that the patient is uncomfortable with the device keeping records of her exercise sessions. If for example, she has not performed the prescribed exercises for the week, she might be reluctant to discuss the issue with her therapist to avoid discomfort. Our wearable system however, transparently presents all exercise information. Is it possible to mitigate this issues in our design?

Acknowledgments

This research is supported in part by the National Science Foundation Award No IIS-0846024. The materials and electronic components for this research are supported by the University of Colorado Engineering Excellence Fund.

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