Making the Physical Therapy Entertaining

An Application Based on Wearable Technology and Mobile Games

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Abstract. In physical therapy, goniometers are used to measure limb movement during restoration exercises. These devices aren't always readily available to therapists, and the exercises themselves are monotonous and offer little motivation for the patients. We have developed a low-cost device prototype we've tested in knee rehabilitation exercises, and developed a framework with which a mobile application can use gathered data from said device, such as is the case of an example game also addressed here, intended to increase patient motivation and commitment when exercising.

Keywords: Physical therapy · Wearable medical devices · Videogames

1 Introduction

Rehabilitation in Physical Therapy helps overcoming physical impairments in order to develop or restore maximum body movement. The main causes that lead people to require physical therapy are ageing, injuries, diseases, and other disorders. It is conducted by a physical therapist and includes: examination, evaluation, diagnosis, prognosis, treatment, and re-examination of a physical movement restriction.

In recent years, some research projects have been exploring the use of wearable technology to monitor physical movement for rehabilitation [1, 2]. Moreover, videogames have been incorporated into the physical therapy process to make it less monotonous [3].

This paper proposes a wearable device that allows physical therapy monitoring with a built in game which dynamics force the player to perform physical therapy exercises, called Funtherapy. Our goal is to provide an entertaining way to perform the tedious movements required in physical therapy, as well as real time monitoring of exercises, in order to prevent injuries while performing these.

J. Bravo et al. (Eds.): AmIHEALTH 2015, LNCS 9456, pp. 148–154, 2015.
DOI: 10.1007/978-3-319-26508-7_15

The main contribution of this research is the accurate measurement of movements that allow physical therapy monitoring, while using videogames to increase the interest on the daily exercises and the motivation of the patient on knee rehabilitation.

The research was done with expert supervision from the School of Physical Therapy at Universidad de Costa Rica (UCR), to assess the system's applicability to physical therapy for knee rehabilitation. Functional testing was also executed in real scenarios, performed by physical therapists. Results were promising, as the experts stated that the system could be applied for constant remote monitoring of patients and to help patients do the exercises as they should.

The rest of the paper is structured as follows: Sect. 2 presents the background and shows some related work. Section 3 describes the design and development of the prototype, to make physical therapy entertaining. Section 4 concludes the paper and points out potential future work.

2 Background

This section describes some examples of wearable technology applications in healthcare and physical therapy.

2.1 Wearable Technology Applications in Healthcare

Advances in technology have enabled the application of wearable technology into healthcare [4]. These applications use wearable medical devices, which can be described as an autonomous, non-invasive system that performs a specific medical function such as monitoring or support [5]. Wearable medical devices are composed of [5]:

- Sensors, either physiological or environmental to monitor health (e.g., body temperature, pulse rate, respiration rate, blood pressure) or surrounding conditions (e.g., temperature, humidity).
- Processing unit and all computational hardware required for input and output of computation of information.
- Customized clothing to attach all the components to the user.

Wearable medical devices include a wide range of sensors such as accelerometers and gyroscopes, smart fabrics, actuators, wireless communication networks, power supplies, and data capture and processing technologies [6]. Moreover, they allow movement that other types of systems restrain.

Alrige and Chatterjee [7] proposed a taxonomy of wearable technologies in healthcare with the goal to characterize the developments in this area. Their taxonomy divides the spectrum in three dimensions: functionality, application, and form. According to this taxonomy, Funtherapy is Single-Sensor, in the functionality dimension. In the application dimension, the system is for monitoring and assistance, so it offers more value for patient more than for therapists. Finally in the form dimension, Funtherapy is an accessory, however, if the mobile application is considered, it is also portable.

2.2 Related Work

Several researches have been conducted to create accurate devices that measure physical movement. For instance, Huang et al. [8] presented a wearable physical therapy support system that gathers patient exercise compliance and performance, and provides visual information for the therapist.

Yurtman and Barshan [9] developed an autonomous system that detects and evaluates physical therapy exercises using wearable motion sensors. They monitor exercises similar in the scope of Funtherpay; however, their algorithm uses a multi sensor approach to do it (we used a single one).

Kimel [10] designed a device to improve patient-therapist communication using a network-based monitoring system. Ananthanarayan et al. [11] presented a similar device. However, their knee support like device allows more than just monitoring, it has a haptic visualization of the knee angle, allowing the patient to measure in a more precise manner the knee angle and perform in a better way the therapy exercises.

Muñoz et al. [12] developed an Arduino based prototype that measures knee movement and angles, using a Led to allow the user to know when the exercise angle is reached.

Nerino et al. [13] developed an unassisted system for post-surgical knee rehabilitation, from which the patients get feedback about the correct positions and executions of the exercises in a mobile app. A similar system for rehabilitation at home was proposed by Ayoade and Baillie [14], where the movement visualizations are displayed in a computer, and the patients get feedback by a color-coded and repetition counter.

The main difference between these proposals and the one proposed by this research is that it provides the user's feedback integrated in the videogame, allowing constant monitoring, and not just some graphic notifications.

Moreover, the videogame follows the exercise dynamics according to the therapist recommendations. Finally, instead of a knee sleeve/support device, we use a small sensor in the ankle to measure knee angles.

3 Design and Development

FunTherapy consists of two main components: a wearable device that tracks the user movements and a mobile application (goniometer and videogame) that gathers information and utilizes the wearable device as an interaction mechanism.

3.1 The Wearable Device

As it was stated by Glaros and Fotiadis [5], every wearable system is usually composed of three main parts: sensors, processing unit, and clothing. This section describes these three components within the context of the Funtherapy system.

The sensor used for this system was one Adafruit's Flora Accelerometer/Compass/Gyroscope Sensor LSM9DS0. This sensor contains a 3-axis accelerometer, a 3 axis magnetometer, and a 3-axis gyroscope. For communication purposes between the wearable and the mobile, we use an HC-06 generic Bluetooth module. As for the processing unit, an Adafruit's wearable electronics platform Arduino Flora was used. And finally, a lithium battery with 2000 milliamps and 3.7 V was also used.

The software runs in a mobile phone and the input are Euler angles [15] in a three dimension system: roll (x-axis, Eq. 1), pitch (y-axis, Eq. 2), and heading (z-axis, Eq. 3). X, Y, and Z in these equations are data gathered from the accelerometer in the corresponding axis.

In the first version of the prototype we used a plastic case to fit all of the components together. However, the case's material is going to be changed in order to increase user comfort while using the device.

3.2 App Design

Since mobile devices have achieved considerable penetration within the general public in recent years, it was decided to develop the framework and test system as a mobile application, such that it could eventually be made available at little to no cost to therapists and their patients along with the corresponding hardware interface.

In the first phase, we worked with professional therapists of the School of Physical Therapy at UCR, simulating the operation of the goniometer, an instrument used for measuring angles on limbs. The app has an interface that shows the movement of the leg flexion and extension, derived from the information obtained through the wearable.

Fig. 1. Goniometer test at 90°

The first tests were carried out with an exercise to work knee flexion and extension: the patient is positioned in a sitting position and is tasked with stretching his leg towards the front, in a 90º (as shown in Fig. 1). The results showed that it was necessary to adjust the measurements, since the goniometer measures angles formed by the tibia and femur, and the wearable is over the tibia. Adjustment corresponds to 5 additional degrees, according to the measurements made by therapists. Wearable measurements were then repeated and compared with the goniometer results, resulting in completely matching results (Table 1).

The second exercise works with the knee flexion and extension in the rear part of the leg. The patient lies down and is instructed to move the leg in the direction of the coccyx, as closest as the muscles allow it. The results match between the wearable and the goniometer, adding the adjustment indicated by therapists.

Table 1. Goniometer vs wearable device test

Wearable	Goniometer	Wearable + adjust
85	90	90
65	70	70
60	65	65
80	85	85
75	80	80

Feedback was requested from the therapists who participated in the study, revealing several potential improvements in the way they interacted with the prototype device, such as being able to modify variables used for exercise measurement.

In the second phase, we designed a game based around classic sidescroller space shooters in which items that the player must catch move towards the player's avatar as he/she performs one of the exercises described previously (in the example, patient must catch the stars, as shown in Fig. 1).

Our decision to use this game was that most of the people that suffer an impairment that forces them to attend physical therapy had some type of interaction with this kind of games. Therefore, we hope that this similarity to a well-known game will engage people in the gameplay, providing the required concentration and immersion.

The game provides therapists with the same control over exercise variables as the developed prototype used in our trials, so that it can be adjusted to the needs of different patients.

4 Conclusions and Future Work

Preliminary results from trials performed with physical therapists indicate it is possible to develop a low-cost device that mimics the behavior of goniometers used for physical therapy applications, with the added benefit of integrating endpoints which other more complex applications can leverage for various purposes.

Due to the scope of the project, in this article we've focused on developing a simple videogame intended to be used for knee rehabilitation, however it should be evident that the project's framework is highly adaptable and allows for a wide variety of applications on physical therapy and other fields at a very low cost.

This could potentially lead to interest for this sort of devices and applications in places where professional tools aren't readily available, such as medical facilities in third world countries.

As for future work, despite the current prototype being in itself a work in progress, there are many projects this basework could spawn, such as determining whether physical improvement of patients can be improved by introducing motivation-inducing game design principles, introducing accessibility features so that therapists can also make use of the system through visual or audio cues, or explore more kind of game archetypes that could be applied to other exercise types.

Acknowledgments. This work was partially supported by CITIC-UCR (Centro de Investigaciones en Tecnologías de la Información y Comunicación) grand No. 834-B4-159 and by ECCI-UCR (Escuela de Ciencias de la Computación e Informatica at Universidad de Costa Rica). We thank professor Judith Umaña Cascante of Escuela de Terapia Física at Universidad de Costa Rica for her support.

References

1. Patel, S., Park, H., Bonato, P., Chan, L., Rodgers, M.: Wearable sensors and systems; home monitoring; telemedicine; smart home. J. NeuroEng. Rehabil. **9**(21), 1–17 (2012)
2. Appelboom, G., Camacho, E., Abraham, M., Bruce, S., Dumont, E., Zacharia, B., D'Amico, R., Slomian, J., Reginster, J., Bruyère, O., Connolly, E.S.: Smart wearable body sensors for patient self-assessment and monitoring. Arch. Public Health **72**(1), 1–9 (2014)
3. Geurts, L., Vanden Abeele, V., Husson, J., Windey, F., Van Overveldt, M., Annema, J.H., Desmet, S.: Digital games for physical therapy: fulfilling the need for calibration and adaptation. In: Conference on Tangible, Embedded, and Embodied Interaction (2011)
4. Raso, I., Hervás, R., & Bravo, J.: m-Physio: Personalized Accelerometer-based Physical Rehabilitation Platform (n.d.) (2010)
5. Glaros, C., Fotiadis, D.: Wearable devices in healthcare. In: Silverman, B.G., Jain, A., Ichalkaranje, A., Jain, L.C. (eds.) Intelligent Paradigms for Healthcare Enterprises. Studies in Fuzziness and Soft Computing, pp. 237–264. Springer, Berlin (2005)
6. Chan, M., Estève, D., Fourniols, J.-Y., Escriba, C., Campo, E.: Smart wearable systems: current status and future challenges. Artif. Intell. Med. **56**(3), 137–156 (2012)
7. Alrige, M., Chatterjee, S.: Toward a taxonomy of wearable technologies in healthcare. In: Donnellan, B., Helfert, M., Kenneally, J., VanderMeer, D., Rothenberger, M., Winter, R. (eds.). LNCS, vol. 9073, pp. 496–504Springer, Heidelberg (2015)
8. Huang, K., Sparto, P.J., Kiesler, S., Smailagic, A., Mankoff, J., Siewiorek, D.: A technology probe of wearable in-home computer-assisted physical therapy. In: ACM Conference on Human Factors in Computing Systems (2014)
9. Yurtman, A., Barshan, B.: detection and evaluation of physical therapy exercises by dynamic time warping using wearable motion sensor units. In: International Symposium on Computer and Information Sciences (2013)
10. Kimel, J.: Thera-Network: a wearable computing network to motivate exercise in patients undergoing physical therapy. In: International Conference on Distributed Computing Systems Workshops (2005)
11. Ananthanarayan, S., Sheh, M., Chien, A., Profita, H., Siek, K.: Pt Viz: Towards a wearable device for visualizing knee rehabilitation exercises. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (2013)
12. Muñoz, D., Pruett, A., Williams, G.: Knee: an everyday wearable goniometer for monitoring physical therapy adherence. In: CHI 2014 Extended Abstracts on Human Factors in Computing Systems (2014)
13. Nerino, R., Contin, L., da Silva Pinto, W.J.G., Massazza, G., Actis, M., Capacchione, P., Pettiti, G.: A BSN based service for post-surgical knee rehabilitation at home. In: Proceedings of the 8th International Conference on Body Area Networks, pp. 401–407. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), Brussels, Belgium (2013)

14. Ayoade, M., Baillie, L.: A novel knee rehabilitation system for the home. In: Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems, pp. 2521–2530. ACM, New York, NY, USA (2014)
15. Pio, R.: Euler angle transformations. IEEE Trans. Autom. Control **11**(4), 707–715 (1966)