A Novel Framework for Physical Therapy Rehabilitation Monitoring and Assessment in Parkinson Disease Patients using Depth Information

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ABSTRACT

Parkinson Disease (PD) is a type of neurodegenerative disease mainly characterised by the progressive declination of motor and cognitive skills. Physical therapies have been shown to be helpful to mitigate the degenerative impact of PD patients by stimulating the patient to maintain activity. However, problems associated to these therapies such as subjective evaluations or lack of accessibility, rise some barriers to professionals and related stakeholders to reach fully functional integrated healthcare systems. In this paper, a novel framework to continuously monitor and assess PD patients in their therapies is presented. This framework is composed of a sensorial system that captures movement information from patients while they perform physical rehabilitation therapies and a tool for processing this information, extracting movement patterns and providing an objective evaluation of the performed exercises. The system has been deployed and tested in a real-world environment with PD patients at different stages of the disease. The evaluation of the system underlined the added value of objective data in measuring patient movement evolution and how this helps in personalizing treatment according to patients needs.

CCS CONCEPTS

• **Applied computing → Health care information systems**; **Health informatics**.

KEYWORDS

Rehabilitation, Depth sensors, Parkinson disease

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1 INTRODUCTION

Recently, there has been a huge effort to deal with societal challenges in order to guarantee sustainability and well-being among population. Mid and long term perspectives show that there will be a significant increase in life expectancy, and unfortunately, also in the number of people affected by associate diseases. According to the World Alzheimer Report, 2018, the number of people living with dementia worldwide is expected to double by 2030, and reach 150 Million by 2050[1]. Thus, public authorities, policy makers, researchers and private businesses should join forces to develop innovative solutions to improve Quality of Life of people affected by such diseases.

There is a growing interest from research, professional and business perspectives in physical activity recognition. The main reason is to have a better knowledge of how the disease is evolving as well as quantify the impact of these activities over patients quality of life. Multiple technological solutions have been proposed for this purpose using novel technologies such as virtual reality (VR) [4] and computer games [1] among others. Some examples include Virtual rehabilitation system[2], Leap Motion[3] or Walkaide system[4]. These tools are able to capture information about the amount of movement of a particular patient. Nonetheless, although there is measurable data, none of these solutions is adequate to follow the evolution of the movement in a continuous, measurable and holistic way. Up to the best of our knowledge, some tools aim to monitor the information with similar approaches, such as Kinetikos[5] or Motognosis[6]. Nevertheless, these approaches are mainly devoted to providing some inertial information to the professionals. Kinetikos consists of a system of sensors attached to the patient's body to provide information about the number of steps and leg traction. This technology makes movement assessments, but it is not a system suitable for constant monitoring due to the difficulty of carrying out a continuous exercise with the sensors attached to the body. Perhaps the most similar work to ours is presented by Motognosis, where the RGB-D information is employed to quantify body data information.

In [2], the HeartHealth platform for Cardiac rehabilitation scenarios was proposed. In this platform, a health-care professional needs to record the exercises that are going to be prescribed to a specific patient using the Kinect camera. Based on these recordings, the system evaluates the movements of the patient while performing the exercises in front of a Kinect camera (and optionally wearing inertial sensors). In order to encourage users to perform the prescribed exercises at home, all of the rehabilitation exercises are presented as a game on the computer screen, where the user must avoid or catch specific items that appear.

In Chatzitofis et al. [3], a similar architecture to [2] was presented, with an emphasis on evaluating exercises where the user may be lying down. In order to improve detection results in these situations, inertial sensors are placed on the user's body parts which are important for the specific exercise. The system is also able to measure upper and lower body orientation and anthropometric parameters, such as body height, limb length, etc.

The work presented in [6] exploits the use of games, in combination with sensors (IMUs and RGB-D sensors), to measure the patients movements during simple game sessions. Finally, in [5, 7] studies about the use of Nintendo Wii and Kinect camera in rehabilitation scenarios is presented.

The added value of the proposed system is that it is able to provide movement evolution data of PD patients based on the exercises performed in the regular therapies with their professional, without the need to interfere in their usual routines and without having to place additional sensors attached to the body. The existence of an advanced interface for monitoring provides the opportunity to the professionals to have objective data, which will help them to customize therapeutic treatments and, indirectly, have data and measurements that can be used for subsequent impact studies of physical rehabilitation therapies in PD. This aspect is totally new, because in the praxis of professionals, although periodic evaluations are made for people affected by PD with standardized and approved scales, these evaluations are totally clinical; objective and measurable data is lacking.

2 PROPOSED SYSTEM

2.1 Methodology

The system presented in this work has been validated within the activities of the European H2020 ICT4LIFE project[7]. This tool has been tested during the lifetime of two pilot deployments in physical rehabilitation rooms at APM[8], where the deployment was made possible thanks to the specific skills and premises of this partner. The interaction between the end-users and the ICT4Life system in this scenario took place in the following way.

This system aims at becoming a 'screening tool' in order to facilitate professionals in obtaining objective data regarding movement evolution. The system can be used for continuous evaluation of the patient physical state, supporting clinical decision making and personalized rehabilitation. With this tool, professionals can track patients evolution, identify weaknesses and therefore customize exercises to strengthen their weaknesses in terms of mobility. The ambition of the proposed system is not to improve the physical skills of a PD, but mitigate the impact (and obtain evidence) of the disease evolution.

Furthermore, data gathered can be employed to increase the scientific knowledge. The main ambition is to demonstrate, in a quantitative way, the positive effect in patients by the therapies, as well as their evolution. Continuous monitoring of patients can help to establish profiles on Parkinson's disease evolution and to develop more detailed studies.

The system was deployed to assess the movement evolution of the Patients, and more specifically, to provide some quantitative metrics that support the physiotherapists in the patient skills evolution, as well as to evaluate the impact on patients' health condition.

The time schedule for monitoring patients in Rehabilitation Room has been organized in 2 waves spanning 3 months: April-May 2018 (1½ month) and October-November 2018 (1½ month). In total, 30 users were involved in the rehabilitation centre:

[1]Strategic Implementation Plan - Strategic Part: https://www.alz.co.uk/research/WorldAlzheimerReport2018.pdf
[2]http://www.walkaide.com/Pages/default.aspx
[3]https://www.leapmotion.com/
[4]https://evolvrehab.com/virtualrehab/
[5]http://www.kinetikos.io/
[6]http://motognosis.com/
[7]https://cordis.europa.eu/project/rcn/199905/factsheet/en
[8]Deployed at Asociación Parkinson Madrid (APM): https://www.parkinsonmadrid.org/

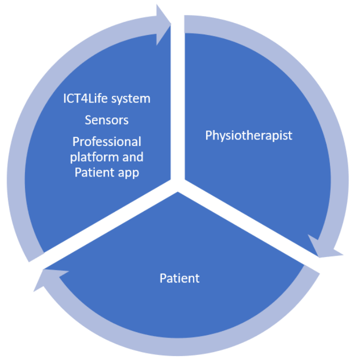

Figure 1: Interaction between the proposed system and end-users in the rehabilitation rooms

- 12 Patients distributed in 7 different groups during the 2 waves. Finally, 10 patients finished the research because two of them leave the physiotherapist's rehabilitation.
- 12 Control patients distributed in 7 different groups during the 2 waves. Finally, 7 of them abandoned the physiotherapist's rehabilitation.
- 6 Physiotherapists (in all waves).
- Validation group: physiotherapist

The ambition of the scheduling (separated waves of testing) was to determine whether a significant change in the patients' health conditions could be observed.

The following criteria were respected for the selection of the users involved in the pilots:

- Willingness to participate
- Gender balance
- Expertise on ICT tools use before diagnosis
- Patients: mild/medium evolution stage; frequent attendees to therapy sessions

The following components and materials were employed:

- RGB-D Sensor
- Smart Bands equipped with Inertial Movement Unit (IMU) sensors.

The specific research techniques to collect data and users' feedback during the pilot tests are comparative among categories of end-users and diseases. The following techniques compose the research methodology that has been used:

- Entry interview
- Periodic assessment questionnaires (every two months).
- Observation grid
- Exit interview

Furthermore, specific personal interviews were used by the researchers during the pilot tests, namely the *Entry Interview*, and *Exit Interview*. These interviews represent the supportive documents collecting relevant information about the users to conduct the social research and to assess the achievement.

The procedure of participants selection, the conditions to implement the interviews, the questionnaires included, the coding and storage procedures were all standardized.

All these research tools have been adapted according to the type of users who were involved in each test.

2.2 System Deployment and Setup

The system needs an initial set-up in order to attain a high reliability. Some steps were performed in order to fix the camera's position in the rehabilitation room, to guarantee high quality skeleton detection. The RGB-D sensors were placed in a tripod at a height of 200 cm (best quality and high range for Kinect is between 190-220 cm) pointing to the front, to cover an area of about 6 meters in depth.

The final position for the camera was determined based on the ability to cover the space where at least 3 persons, standing next to each other, could perform the exercises without interfering with each other. Afterwards, the developed tool (which will be presented in more detail in the next section) provides a functionality to manually fix the best positions for the patients based on the real time detected skeletons. Additionally, this configuration provides enough space to the physiotherapists to perform the exercises with only a few occlusions in the field of view of the camera.

Finally, in order to avoid process repetitions every time that the camera is not in its position, some markers were placed on the room floor to indicate the ideal positions for both patients and cameras. This process allowed the physiotherapists to move the camera if some different sessions were taken place in the room, without interfering with the rehabilitation schedule.

Voice-commanding capability was added to the software so that physiotherapists can change the exercise that the software is evaluating by simply speaking to the Kinect sensor. Then, a second set-up is necessary to define a common exercise name easy to pronounce and learn for the physiotherapists to make possible this automatic change without errors.

2.3 Rehabilitation Tool

The rehabilitation tool was designed with the aim of providing an objective analysis of patients movement to physiotherapists. In the short term, the tool provides real-time feedback about the performed exercises. In the long term, these real-time measurements are summarized for each person, thus providing objective movement evolution results across sessions. These results can supplement physiotherapists decision-making process regarding the exercise plan of the patients.

The tool is organized into three different sections: a) Exercise Evaluation, b) Angle Measurements and c) Set Positions. The Exercise Evaluation part uses models trained on specific exercises in order to evaluate users' performance. This option involves recording the exercises in Kinect .xef files, annotating each repetition by hand and then training a model using machine learning techniques in order to evaluate each exercise. Because of the highly time-consuming aspect of this approach, the Angle Measurements mode (b) was developed for simplifying this process, and was eventually the preferred mode of usage for this tool. Although in this mode the list of supported exercises must still be known beforehand, no recording, annotation or model training are required. This mode involves defining a set of important angles for each exercise, which the tool calculates in real-time using the Kinect tracked skeleton for each person. The Set Positions section allows the user to set three positions on the floor, and link them with a user id, in order to identify who was standing in each position and to have a matching across different rehabilitation sessions of the same person. This allows the results of different sessions to be linked together.

Regarding the process the Angle Measurements mode utilizes to calculate the angles, first the anatomical planes of the human body are calculated (sagittal, frontal and horizontal). Then, for each exercise, a set of important angles has been provided by the physiotherapists, and the system calculates these, based on the relation between specific joints of the human body and the anatomical planes. For example, if one exercise requires the lateral movement of the hands to be recorded, the system uses the shoulder and elbow joints to define the hand movement, and the angle between the vector defined by these two points and the sagittal plane is measured by the system. Finally, a set of rules is applied to the detected motion, to verify that the exercise is being properly executed, and a corresponding warning is shown in the user interface when the motion violates the rules. For instance, in an exercise where the user must keep the knees bent, the rules would contain an upper and lower limit for the angle the knees form, and a warning would be displayed if the user did not position the legs properly. A snapshot of the interface while a physiotherapist is performing an exercise can be seen in Figure 2, in which the system displays real-time evaluation results.

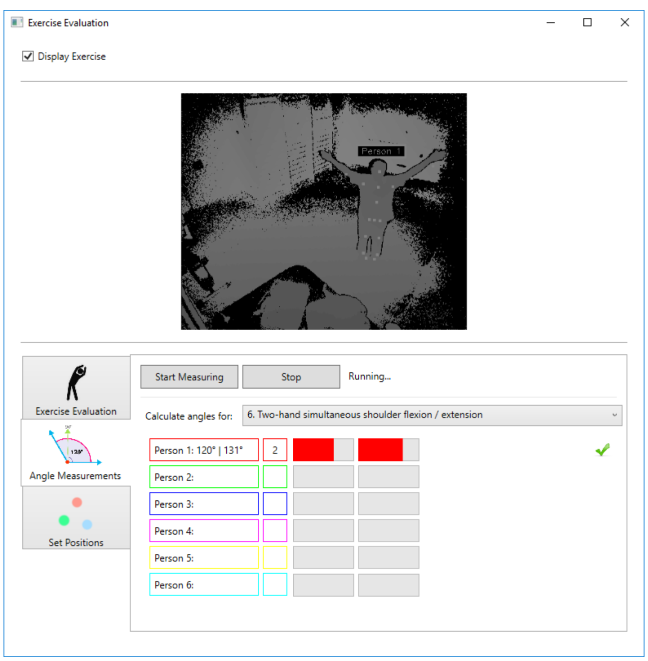

Figure 2: Rehabilitation Tool User Interface

3 SYSTEM EVALUATION

3.1 Exercise Evaluation Results

As previously discussed, the system was installed at the APM premises and recorded real-life rehabilitation sessions. Besides real-time evaluation results, the system also produced a session summary for each session the user participated during the period of deployment. Figure 3 shows the produced summary for a user, for the exercise *Two-hand alternating shoulder flexion / extension*. In the upper part of the figure, the angles of the right (blue) and left (green) hands are shown, while in the bottom, the corresponding duration (in seconds) of each repetition is shown.

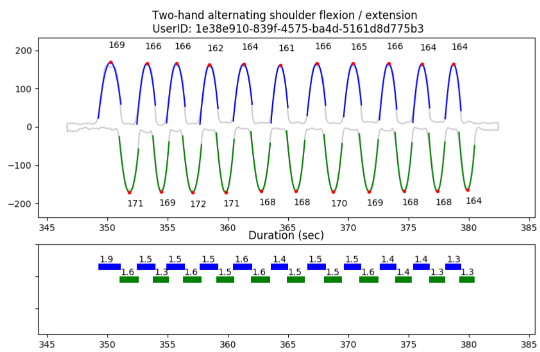

Figure 3: Produced user summary for the exercise *Two-hand alternating shoulder flexion / extension*

At the end of the deployment period, these intermediate per session summarized results were analyzed in aggregate, so that final conclusions about each user can be drawn. Figure 4 shows the aggregate evaluation results for a specific user when performing the exercise *Trunk rotation with arms attached to body*. As we can see, based on the evaluations across 4 different sessions, this user appears to experience difficulty when rotating to the left, as the left-side angle of rotation was consistently lower than the right side.

3.2 System Acceptance

During the second wave of pilot tests at the rehabilitation room, the voice command was integrated, in order to allow the system to recognize automatically the patients' physical exercises. This voice command was appreciated by professionals because it allowed them to use the technology having the hands free (really necessary for therapeutics dealing with patients affected by Parkinson's disease). However, due to the fact that it was introduced only in the second wave and some technical problems were reported by professionals, physiotherapists had the feeling that this voice commands have more uses that may be further explored.

After using the ICT4life system, 54,54% of the involved professionals considered that ICT4Life helps them to save time, 36,36% of them consider that they do not save time and 9,09% does not have a clear opinion on this issue. In an online survey (51 answers), professionals answered up to 90% that the system will support them in being more efficient due to the added information for each patient.

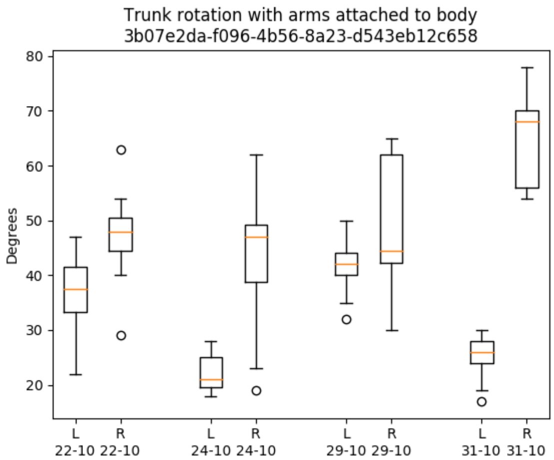

Figure 4: Aggregate user results produced by the system

Regarding the general opinion on the developed Rehabilitation Tool, 80% of patients rated it as good and 20% of patients assessed it as neither good nor bad. Finally, the Kinect camera was rated with a 90% acceptance during the pilots, due to its non-intrusive way of record only skeleton data without the use of images.

4 DISCUSSION AND FUTURE WORK

The professionals in the rehabilitation scenario were really active users of the ICT4life system and they had reported possible improvements and developments for the future. A general positive feedback was given to this tool, due to the fact that having objective information allows them to see the patient evolution in short period of time, and personalize the therapies according patient's needs. Today, professionals make an assessment once per year, as discussed before, using standardized scales in a clinical way, without objective and accurate data.

The voice commanding capability added to the kinect and tested in the rehabilitation room is really important, according to health professionals, due to the movement problems of Parkinson's patients and therefore assessed positively (especially by physiotherapists who need free hands to work). The patients' evolution and recommendations made by the system taking into account the data provided is an important potential value for the health professionals. Moreover, rehabilitation recommendations by professionals are very useful for patients' rehabilitation practices at home and this will be a possible use in the future. Objective data about the patients have also been assessed positively by the physiotherapist, because of the innovative aspect and because they allow them to personalize the patients' treatment.

5 CONCLUSIONS

In this paper, a novel framework for continuously monitoring and assessing PD patients during their rehabilitation therapies is presented. This system has been deployed, validated and tested in a real-world environment with PD patients and archived high acceptance, both from the patients and the professionals. Furthermore, the professionals underlined the added value of objective data for measuring the patient evolution and perform personalized treatments and therapies according to patients' needs.

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