ExerciseCheck: Remote Monitoring and Evaluation Platform for Home Based Physical Therapy

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ABSTRACT

A daily exercise program designed by a physical therapist or physician may be crucial for a patient's physical rehabilitation. However, when these exercises are performed at home without the supervision of the therapist, they may not be as effective as when performed in the presence of the therapist. In this paper, we present ExerciseCheck, a remote monitoring and evaluation platform for individuals involved in a home exercise program. The goal of the platform is to give patients feedback about their performance and, if needed, and how they should adjust their movements. ExerciseCheck is designed for a therapist to remotely monitor a patient in real time, enabling the therapist to give instant feedback or further instructions. To demonstrate how ExerciseCheck is used with a Kinect interface, we tested it with two exercises – arm raise and squat. The results highlight the potential benefits the proposed platform may have in home-based physical therapy, enabling communication between the patient and the therapist.

CCS CONCEPTS

•**Human-centered computing** → *User models; Usability testing;* Interaction design process and methods;

KEYWORDS

Home based Physical Therapy, Microsoft Kinect, Remote Monitoring, Motor Disabilities, Motion Capture Technology

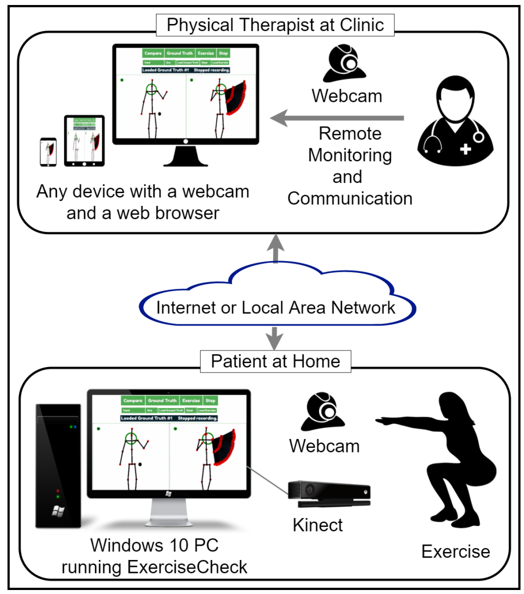

Figure 1: A block diagram of the proposed platform ExerciseCheck. The patient exercises in front of a Kinect, which is connected to a desktop computer. ExerciseCheck records the patient's movement trajectory using the Kinect and provides visual feedback to the patient on the computer screen. At the same time, the physical therapist can monitor the movement of the user through a web browser, which visualizes the motion. There are also webcams available on both sides to facilitate the verbal and visual communication. The therapist can give instant feedback or additional instructions using the video chat.

1 INTRODUCTION

Physical therapy is most effective if the prescribed exercises are performed properly under the regular assessment of a physical therapist (PT). In conventional physical therapy, a PT provides direct care during a course of treatment, including home-based exercises to transition care to their home and community environments to continue the recovery process [4]. It has been shown that only one third of individuals with motor disabilities perform their daily exercises properly [12]. This deficiency delays the rehabilitation of physical function and prolonged symptom increases the risks of adverse consequences such as musculoskeletal injury or motor disabilities. The application of motion capture technology to address the shortcomings of conventional physical therapy has become a growing area of interest. The use of the Microsoft Kinect, as a low cost, non-intrusive monitoring device for clinical purposes, has been investigated in the literature [1, 3, 8, 15]. Kinect systems offer skeletal tracking capabilities, enabling interactive and motivational exercise training, motion modeling, and quantitative analysis. Prior works typically either require the full-time presence of the therapist, or with no presence at all. Tele-rehabilitation systems can partly address the physical absence of the therapist by providing a convenient solution, but they do not necessarily ensure an accurate and comprehensive approach to support the patient.

We here propose a remote rehabilitation platform that allows users to perform their regular routines at home using the affordable Microsoft Kinect. ExerciseCheck integrates the concepts of

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quantitative evaluation and feedback, and tele-rehabilitation. ExerciseCheck presents interpretable exercise evaluations to patients and the physical therapist in real-time. The therapist can intervene when the patient requests help or when it is deemed necessary by the therapist. The therapist can monitor the 3D positions of specified anatomical landmarks of the user and evaluate the user's performance either based on qualitative observation or more precise quantitative measurements provided by ExerciseCheck. To make these interventions possible, ExerciseCheck uses a Kinect on the patient's side and a device with a web-browser on the therapist's side, which can be a PC, laptop, or a cell phone. These simple hardware components make ExerciseCheck a flexible and convenient platform for both patient and therapist (Fig. 1). We examined ExerciseCheck with two basic exercises used in physical therapy. The results confirm the potential benefit of employing our design in physical therapy.

1.1 Related Work

Physical rehabilitation programs require the patient to carry out repetitive exercises at home as instructed by the physical therapist. However, patients often find their daily routine hard to follow, not engaging, and confusing. On the other hand, the physical therapist is limited to evaluate the performance of the patient based on qualitative observations on the patients' visits to therapy center. Recent attempts to address motivational issues, the feasibility of using Kinect, quantitative evaluation, and lack of therapy presence are summarized in this section.

Motivation. Making home-based therapy interesting to patients is important. The Kinect in connection with "serious games" has been used as a motivational tool for physical therapy. Kinect-o-Therapy, developed by Roy *et al.* [9], for example, aims at addressing three key elements of effective rehabilitation – repetition, motivation and feedback.

Accuracy of the Kinect. The accuracy of the Kinect to serve the physical therapy purposes has been always the first concern of the researchers. Kurillo *et al.* has examined the accuracy of the Kinect by comparing its results with marker-based motion capture system[5]. We have also compared the result of the trajectory of few upper body exercises with the accurate Proficio robotic arm [11].

Quantitative Assessment. Incorporating motion analysis technology into physical therapy enables quantitative assessment of a patient's body motion. Vakanski *et al.* proposed a mathematical model for quantitative evaluation of exercise at home [14]. It employs an artificial neural network to retrieve the trajectory of the motion and evaluates the consistency of the motion by comparing it to a reference trajectory. This sort of quantitative analysis of the performance during an exercise can be later employed in the rehabilitation plan. For example, we proposed a method to dynamically adjust the difficulty level of physical exercises in the later trials based on these quantitative performance analysis [10].

Tele-rehabilitation has been proposed to address the physical distance between a patient's clinic and home [6, 7]. Kurillo *et al.* [6] designed a tele-rehabilitation system based on the Microsoft Kinect that provides motion measurements for the upper body. This work is closely related to our own. Our system might be easier to install in a clinic because it does not require any software setup on the therapist's side.

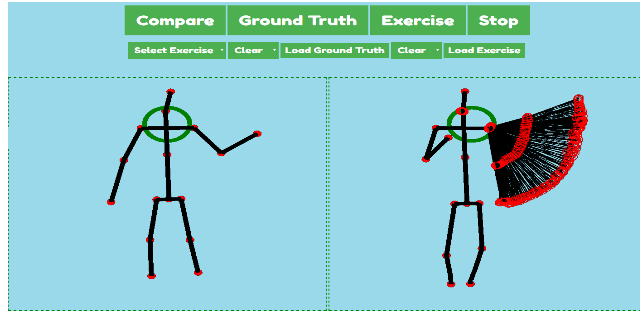

Figure 2: The graphical user interface shows the movement of the body during the exercise on the left and the trajectory history on the right. Interface buttons on the top enable the user to choose, record, or compare exercises.

2 METHOD AND SYSTEM

In this section, we first describe how ExerciseCheck (Fig. 1) would be used in a physical therapy program and then how its analysis component works. We explain how the Kinect is incorporated to provide ExerciseCheck with the motion trajectories, and how this turns into an informative evaluation both for the patient and the therapist. Lastly, we describe our system architecture and how the data transmission from the patient to the physical therapist works.

2.1 Physical Therapy with ExerciseCheck

The physical therapist initially prescribes an exercise and asks the patient to practice the exercise multiple times while the therapist is observing the movements carefully. Once the therapist assesses that the patient is capable of correctly performing the exercise, the patient is asked to perform the exercise in front of the Kinect. At that time, ExerciseCheck records a *reference trajectory* for this exercise. The reference trajectory consists of the trajectories of specified body landmarks. Our platform is capable of recording multiple reference trajectories so that different exercises can be represented.

When the patient repeats a given exercise at home, ExerciseCheck captures the trajectory of the same landmarks and compares them with their references using Dynamic Time Warping (DTW) [2]. Both the patient and the physical therapist can see the trajectories of the reference and current positions of landmarks during the exercise as shown in Figure 2. This feature helps users to observe their mistakes and motivates them to put more effort toward moving more similarly to the reference. Furthermore, it enables the therapist to monitor the patient remotely in real time.

After each trial, ExerciseCheck presents the result of the evaluation to both the patient and the physical therapist. If the patient is performing an exercise incorrectly or is confused and cannot follow the instructions, the therapist can intervene to resolve the confusion by a video connection to the patient.

2.2 Data Collection with the Kinect

The Kinect is capable of "Skeletal Tracking" which allows it to recognize people and map up to 25 joints on their bodies. ExerciseCheck uses the Skeletal Tracking feature of the Kinect to locate the joints of the user and track the user's movements in 3D space. To be recognized by ExerciseCheck, the user simply needs to be in front of the Kinect, making sure the Kinect sensor can see the user's head and upper body. No specific pose or calibration action needs to be taken for a user to be tracked. In default range mode, the Kinect can see people standing between 0.8 meters (2.6 feet) and 4.0 meters (13.1 feet) away. Users will have to be able to use their arms and legs at that distance, suggesting a practical range of 1.2 to 3.5 meters. The infrared emitter of a Kinect sensor projects a pattern of infrared light. This pattern of light is used to calculate the depth of the person in the field of view, allowing the recognition of different users and different body joints [1] .

ExerciseCheck uses extraction of the trajectory of the following points (Fig. 2) to represent the movement of the body:

- Wrist, elbow and shoulder of left and right side,
- Neck and spine
- Ankle, knee and hip of left and right side.

2.3 Evaluation

ExerciseCheck employs Dynamic Time Warping (DTW) to compare the reference trajectory from supervised exercise recorded earlier with PT to the practice trajectory from unsupervised exercise at home. DTW aligns the time sequences in a non-linear fashion to find an optimal match between them. ExerciseCheck reports two evaluation measures for all exercises: the *error,* which is the level of dissimilarity between two trajectories computed using DTW (Fig. 3), and the *speed ratio,* which is the inverse of the ratio between the time it took the patient to perform the practice exercise and the time it took the patient to perform the reference exercise. We deployed the normalized error in order to eliminate the impact of exercise duration on the final result. However, different error values are expected based on each exercise and physical ability of the patients. After a few trials, when the therapist gained an understanding of these values, they will determine which error values should be considered acceptable. In addition, these error values can be utilized as measure of progress over time.

Depending on the exercise, different evaluations and performance metrics might be needed. ExerciseCheck allows implementation of other evaluation mechanisms based on the trajectory of the captured landmarks, as physical therapist may desire. Additional analysis for each specific exercise and the ability of ExerciseCheck to recognize the users' mistakes are discussed in Section 3.

2.4 ExerciseCheck Architecture and Data Transmission

When patients are performing their daily routine, all evaluation results and trajectories of the their movement are simultaneously sent to the therapist's side of the platform (typically located in the clinic), so that the therapist can monitor the patient's home-based exercise and give feedback and further instructions on the spot. ExerciseCheck is built using Node.js to transmit data. Node.js [2] is an open-source, cross-platform JavaScript run-time environment for developing a diverse variety of server tools and applications.

Our use of Node.js makes our design highly modular, event-driven and most importantly allows it to be accessed from any device that is capable of running a modern web-browser, such as Google Chrome or Mozilla Firefox. The patient's side requires a computer, where ExerciseCheck must be installed, and Internet/local area network (LAN) access. The Kinect sensor connects to the PC via USB 3.0. When ExerciseCheck is run, it can be accessed using the web-app interface by pointing the browser to the IP address of the PC both locally or via the Internet. The physical therapist can use any device (a mobile phone, a Microsoft/Apple/Linux laptop or desktop) to connect with ExerciseCheck through a modern web-browser. The system allows physical therapist to monitor data and communicate with patient simultaneously using the webcam feature through the browser itself. The use of a separate webcam instead of the audio streaming of the Kinect avoid any installation complexity or delay in the processing or in the network. The ease of installation and accessibility of our design makes it straightforward for anyone to employ our system.

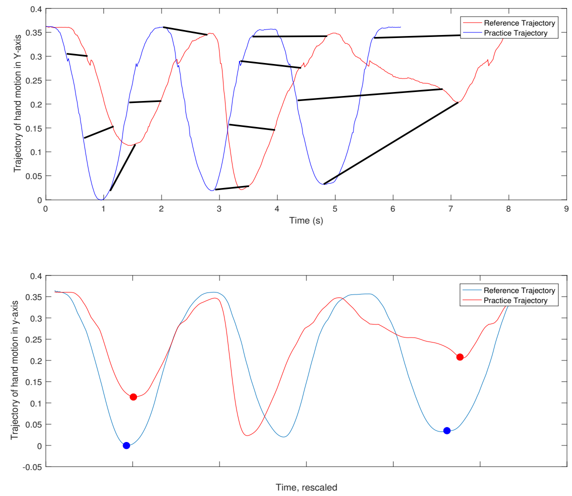

Figure 3: Comparison of the reference trajectory (blue) with the practice trajectory (red). The y-coordinates of a 3D landmark on the subject's hand is plotted per units of time. (a) We first show the mapping produced by Dynamic Time Warping for the two time sequences in the top figure. (b) We show the rescaled trajectories that account for the different speeds at which reference and practice movements were performed in the bottom figure. Rescaling facilitates the visualization of the amplitudes of motion alone. There is no specific time value on x-axis, since the trajectories are stretched or compressed in time, and so best matching locations (y-coordinate of hand) on both trajectories are not reached at the same time. Two sets of points are highlighted by red and blue circles to indicate the difference in amplitude between the reference and practice trajectories.

3 EXPERIMENT

In order to assess our designed platform ExerciseCheck, we conducted an experiment with two healthy subjects whom we asked to perform arm raising and squatting exercises. First the participants were instructed to perform the exercises correctly, so that ExerciseCheck can capture the reference trajectory of their movement. Next, they repeated the exercise, but now making common

[1] https://msdn.microsoft.com/en-us/library/hh973074.aspx
[2] http://www.javaworld.com/article/2079190/scripting-jvm-languages/6-things-you-should-know-about-node-js.html

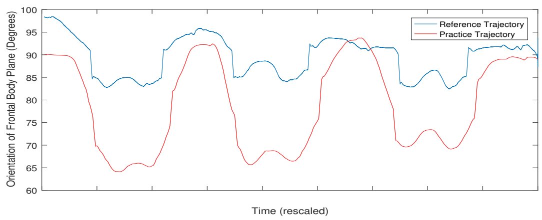

Figure 4: This figure illustrates how our platform evaluates the movement based on the orientation of the body. The user should not lean forward during the squat exercise, as shown in the reference trajectory (blue curve). However, the red curve warns the user of this incorrect movement during the practice exercise.

mistakes that the platform is supposed to detect. There was not any noticeable delay in the processing or network, so that during the experiment, all information was shown on both the patient side and the physical therapist side, allowing an intervention from the therapist side. After each exercise, dynamic time warping was applied to compare the practice trajectory with its corresponding reference trajectory and compute a value of error that represents their dissimilarity. Then the trajectories were rescaled in time, so that the user and the therapist can visually observe the pattern of movements. In addition, the speed ratio was calculated.

For the first exercise, we were interested in checking the extent participants raised their arm in the reference and practice exercises. A comparison of hand motion is shown in Figure 3. The normalized error between trajectories was 0.0609; the speed ratio 0.69.

For the next exercise, the participants were asked to do repeated squats. Squat is a typical exercise that prescribed to patients with knee or hip muscle disease. We considered the squat exercise at three difficulty levels to demonstrate how the therapist might modify the exercise based on a patient's ability [13]. At the first level of difficulty, the patient is supposed to sit on a chair multiple times. In the next level, the patient is asked to stop midway and do a "mini squat." The physical therapist may prescribe the third level, a "full squat," depending on the patient's ability.

We here report results for the first level of difficulty of the squat exercise. In this exercise, patients should not lean forward while sitting. In the practice exercise, we asked our participants to make this mistake and then evaluated how our platform reported the incorrect movements.

The results, as shown in Figure 4, indicate the capability of our ExerciseCheck platform of highlighting incorrectly performed movements. With ExerciseCheck, we were able to detect the leaning-forward mistake, based on the orientation of the participant's body in front of the camera. When the user is in stand up position, the "orientation angle," which is defined as the angle that the vertical body axis makes with the floor, is approximately 90 degrees. The orientation angle should not vary largely as the user is sitting, shown in blue in Fig. 4 for the reference trajectory. However, the orientation angle decreased significantly each time the participant sat down, as shown in red in Fig. 4 for the practice trajectory, indicating the participant was leaning forward.

4 CONCLUSION

We presented ExerciseCheck, a remote monitoring and evaluation platform, developed to provide more reliable care with reduced time cost to patients and physical therapists. With ExerciseCheck, patients receive instructions and evaluations on their exercises while physical therapist can monitor the patient's performance remotely and provide beneficial guidance. The flexible and extendable platform can further incorporate of additional evaluation measures to assist the physical therapist build gamificated strategies to adjust exercises intensity based on their recovery progress.

The results of our experiment confirmed the capabilities of ExerciseCheck in delivering the required assistance in home-based therapy. Our next step will be to conduct a similar experiment with the participation of individuals undergoing physical therapy. We will also make our code publicly available soon, so that ExerciseCheck can be further utilized by other researchers. Making the first prototype of ExerciseCheck is the other direction we are pursuing, so that it can be actually used by patients. We hope that this platform can provide the interactive environment needed for the patients to receive the maximal benefit from a home-based therapy.

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REFERENCES

[1] Ilktan Ar and Yusuf Sinan Akgul. 2013. A monitoring system for home-based physiotherapy exercises. In *Computer and Information Sciences III*. Springer, 487–494.

[2] Donald J Berndt and James Clifford. 1994. Using dynamic time warping to find patterns in time series.. In *KDD Workshop*, Vol. 10. 359–370.

[3] Yao-Jen Chang, Shu-Fang Chen, and Jun-Da Huang. 2011. A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. *Research in Developmental Disabilities* 32, 6 (2011), 2566–2570.

[4] Ravi Komatireddy, Anang Chokshi, Jeanna Basnett, Michael Casale, Daniel Goble, and Tiffany Shubert. 2014. Quality and quantity of rehabilitation exercises delivered by a 3-D motion controlled camera: A pilot study. *International Journal of Physical Medicine & Rehabilitation* 2, 4 (2014).

[5] Gregorij Kurillo, Alic Chen, Ruzena Bajcsy, and Jay J Han. 2013. Evaluation of upper extremity reachable workspace using Kinect camera. *Technology and Health Care* 21, 6 (2013), 641–656.

[6] Gregorij Kurillo, Jay J Han, Alina Nicorici, and Ruzena Bajcsy. 2014. Tele-MFAsT: Kinect-based tele-medicine tool for remote motion and function assessment. *Stud Health Technol Inform* 196 (2014), 215–21.

[7] Anup K Mishra, Marjorie Skubic, and Carmen Abbott. 2015. Development and preliminary validation of an interactive remote physical therapy system. In *37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. 190–193.

[8] Hossein Mousavi Hondori and Maryam Khademi. 2015. A Review on Technical and Clinical Impact of Microsoft Kinect on Physical Therapy and Rehabilitation. *Journal of Medical Engineering* (2015).

[9] Anil K Roy, Yash Soni, and Sonali Dubey. 2013. Enhancing effectiveness of motor rehabilitation using Kinect motion sensing technology. In *IEEE Global Humanitarian Technology Conference: South Asia Satellite (GHTC-SAS)*. 298–304.

[10] Elham Saraee and Margrit Betke. 2016. Dynamic Adjustment of Physical Exercises Based on Performance Using the Proficio Robotic Arm. In *Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 8.

[11] Elham Saraee, Kratesh Ramrakhyani, Ashutosh Sanan, Saurabh Singh, and Margrit Betke. 2016. The Kinect Versus The Proficio: Measuring Hand Position During Exercise Monitoring. In *Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments*. ACM, 88.

[12] Marianne Shaughnessy, Barbara M Resnick, and Richard F Macko. 2006. Testing a model of post-stroke exercise behavior. *Rehabilitation Nursing* 31, 1 (2006), 15–21.

[13] Diane Dalton Jonathan Venne Terry Ellis, Tami Rork DeAngelis. 2016. Be active and beyond. https://www.apdaparkinson.org/uploads/files/Be-Active-Book_For-Web-90o.pdf. (2016).

[14] A Vakanski, JM Ferguson, and S Lee. 2016. Mathematical Modeling and Evaluation of Human Motions in Physical Therapy Using Mixture Density Neural Networks. *Journal of Physiotherapy & Physical Rehabilitation* 1, 4 (2016).

[15] Qifei Wang, Gregorij Kurillo, Ferda Ofli, and Ruzena Bajcsy. 2015. Remote health coaching system and human motion data analysis for physical therapy with Microsoft Kinect. *arXiv preprint arXiv:1512.06492* (2015).