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Development of a Kinect-based exergaming system for motor rehabilitation in neurological disorders

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Abstract. The development of videogames for physical therapy, known as *exergames*, has gained much interest in the last years. In this work, a sytem for rehabilitation and clinical evaluation of neurological patients is presented. The Microsoft Kinect device is used to track the full body of patients, and three games were developed to exercise and assess different aspects of balance and gait rehabilitation. The system provides visual feedback by means of an avatar that follows the movements of the patients, and sound and visual stimuli for giving orders during the experience. Also, the system includes a database and management tools for further analysis and monitoring of therapies. The results obtained show, on the one side, a great reception and interest of patients to use the system. On the other side, the specialists considered very useful the data collected and the quantitative analysis provided by the system, which was then adopted for the clinical routine.

1. Introduction

Since the advent of video game consoles, a large number of devices have been created to provide new forms of gameplay different to the traditional joystick. These devices (dance pads, bikes, motions sensors, etc.) seek to immerse the player in the virtual world through their body movements. These devices have gained great popularity in recent years in a new type of software so-called *exergames* [1]. This new kind of games encourages body movement and motor abilities by using the whole body as a control device. The exergames are part of the field of *serious videogames*, defined as applied computer applications designed for a primary purpose other than mere entertainment, such as training, education, health care and others [2, 3].

In the field of medical clinic, different studies indicate the positive effects of exergaming on health-related behavior changes [4]. Here, the combination of games and exercise equipment allows the creation of systems that collects data during the exercises. This turns out to be very interesting for the medical staff given that the movements and evolution of the patients can be evaluated in an objetive manner. The range of applications is very wide, from promoting physical activity in children, middle-aged and ederly people up to the rehabilitation of patients with brain damage and neurodegenerative diseases [5, 6].

Among the different input devices used to interface with the game systems, one that has received great attention is the Microsoft Kinect. This hardware features an infrared depth sensing camera that capture the full body movements of a person in a 3D space, an RGB camera that provides a color image of the scene and a microphone array for voice recording [7]. Basically, the applications carry out the markerless body tracking and this information directly controls a virtual character on screen, which represents the pose and movements of the user.

Using this device, different medical applications of exergames were proposed in the last years. Following spinal cord injuries, a number of systems were designed to train balance of the upper body [8, 9, 10]. In [11], the system is adapted to home-based rehabilitation, where it first records the movements in the hospital setup and then it evalutes the performance of the users in their homes. Two recent in-depth reviews of health care and rehabilitation applications were presented in [12, 13].

In this article, a Kinect-based sytem with three exergames is designed to evaluate different psychophysical rehabilitation exercises of neurological patients. The system provides visual feedback to the user by means of an avatar (virtualisation of the patient) in the screen that follows his/her movements. Also, it gives the orders using sound and visual stimuli, supplementing the benefits of the experience. Finally, a quantitative analysis of the movements is carried out by saving the joint positions of the skeleton in a database, which allows to follow the evolution of the therapy.

The article is organized as follows. Section 2 describes the clinical routines that were proposed by the therapeutic specialists, the interface and funcionalities of the developed system and the hardware setup in the medical centre. Section 3 presents the experimental conditions and results obtained by the patients. Finally, Section 4 resumes the conclusions of this work and gives some ideas about future work.

2. Methodology and developed tools

2.1. Medical institution and exercises

This work was carried out on the Rehabilitation and Research Centre "Dr. Esteban Laureano Maradona" located in Santa Fe city (province of Santa Fe, Argentina). One of the main tasks is the rehabilitation of sub-acute patients which are clinic and neurologically stable, who do not require hospitalization but need an intense rehabilitation plan. In this context, under the strict supervision of a physiotherapist of the institution, diverse routines for balance and gait rehabilitation were defined and developed [14, 15]. The studies were carried out at the facilities of the institution, which can be seen in Figure 1. All the patients signed informed consent for the studies.

2.1.1. Exercise #1

The therapeutic objective of this exercise is to train the patient to rest his/her weight on the hips, on either side. Historical records of this exercise can be used to measure the treatment evolution of hemiplegic patients.

For this exercise, the physiotherapist set the goal angles between the neck and the trunk. In order to perform the exercise in a ludic way, the proposed "game" presents to the patient a series of coming balls (placed at the desired angles) that he/she must avoid by leaning the trunk towards where a green arrow indicates. The patient should reach the goal angles to fulfil the exercise. The achieved angles are recorded at every time, and these records are later analysed by the specialists.

In Figure 2, the scene is presented and the balls arrangement at different angles (left and right sides) can be appreciated. The angles can be set every $12 - 15$ degrees, also the number of repetitions and the time among repetitions are configurable. In each repetition of the exercise,

Figure 1: Facilities in the rehabilitation centre.

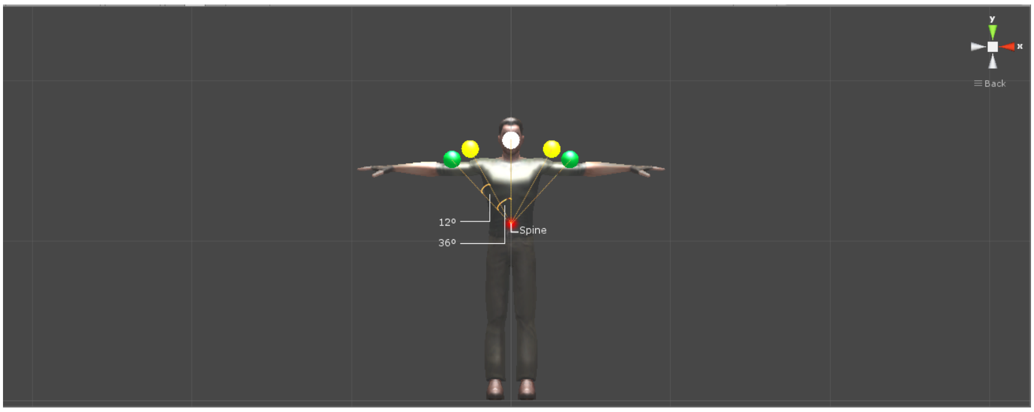


Figure 2: Scene configuration for exercise #1.

the performance is marked as successful, partially successful or not successful. The angle is calculated in the $x - y$ plane using the information of the spine and shoulder center points.

2.1.2. Exercise #2

In this exercise, the patient should train his/her stability while flexing the legs. The patient practices the gait positions in place, that is, displacements are not performed. This training is important in order to correct the foot drag, present in neurological patients. Furthermore, the exercise can be enhanced if the patient has upper-limbs motor skills. In this second scheme, the patient should raise the right hand together with the left leg, and vice versa. This provides a proprioceptive stimulus for scapulo-pelvic coordination.

The game presents an avatar in a scene, in which some balls are rolling towards the patient. The goal is to avoid the balls by raising one foot per time. To reach a successful performance, the foot should be raised up to the level previously fixed by the expert. All the session is registered for a more exhaustive evaluation, regardless the success in the game. Similar to Exercise #1, the number of repetitions and the time among repetitions are configurable (essential to prevent the patient to wear down quickly). If the motor skills will be evaluated, the scene can includes a ball that should be reached with the opposite hand to the raised foot, at the level of elbow,

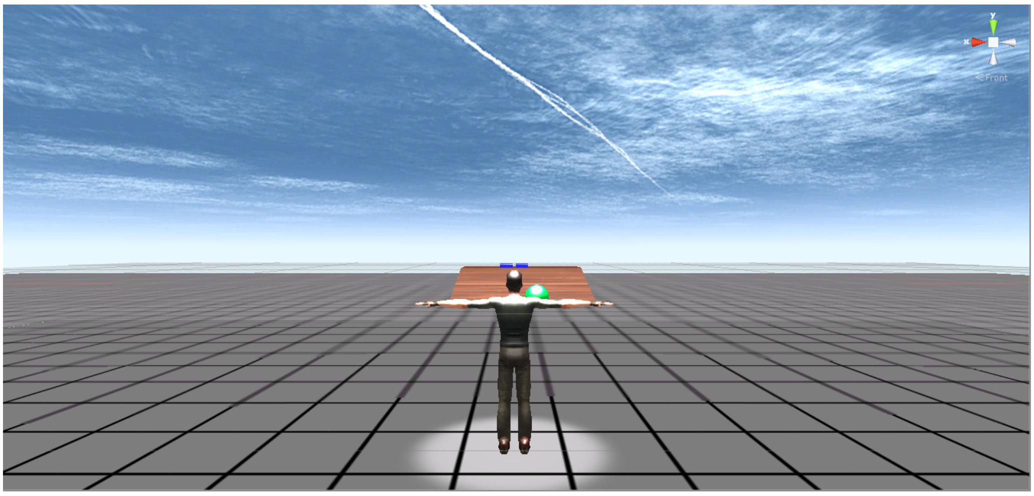


Figure 3: Example for Exercise #2.

shoulder or head.

In addition, it is possible to configure an audible signal to indicate the right moment to raise the foot. This is useful to avoid overload in patients with stability problems and also to estimate the response time to the sound stimulus. Figure 3 shows a scene with the described elements.

2.1.3. Exercise #3
This exercise is oriented to train the pre-gait and it starts with the patient standing and both feet aligned. The patient should do one single step to the front and then, should step the other foot to line up the feet. This is repeated three times. Next, the patient should return to the initial position using the same sequence of steps. Depending on the patient, this can be performed in reverse or forward (after a 180° rotation). In both cases, the objectives are to generate a motor engram about the pre-gait process and to train the patient memory to remember step distances and sequence.

For this exercise, the scene has a series of colour platforms in which the patient should perform the pre-gait. The avatar is semi-transparent to improve the visualization and the starting foot (previouly fixed by the expert) is indicated on screen. Similar to previous exercises, the data are registered for later analyses. Figure 4 presents a scene of the Exercise # 3 in which the colour platforms can be seen.

2.2. Modules
The software of the complete system was conceived in three parts: the *administration* module to configure the exercises; the *registration* module to deal with medical record of patients and the *core* module that includes the processing of the acquired depth images during the rehabilitation routines. There is also a control block that monitors physical exercises fulfilment while collects relevant information.

2.2.1. Administration module The administration module allows the expert to select and fix the parameters of the exercises for each session, according with the type of patient, physical demand, etc. Here, the expert can configure some messages in order to graphically notify the performance to the patient while a physical exercise is running. Also, the information on successes and failures (shows when the routine ends) can be set.

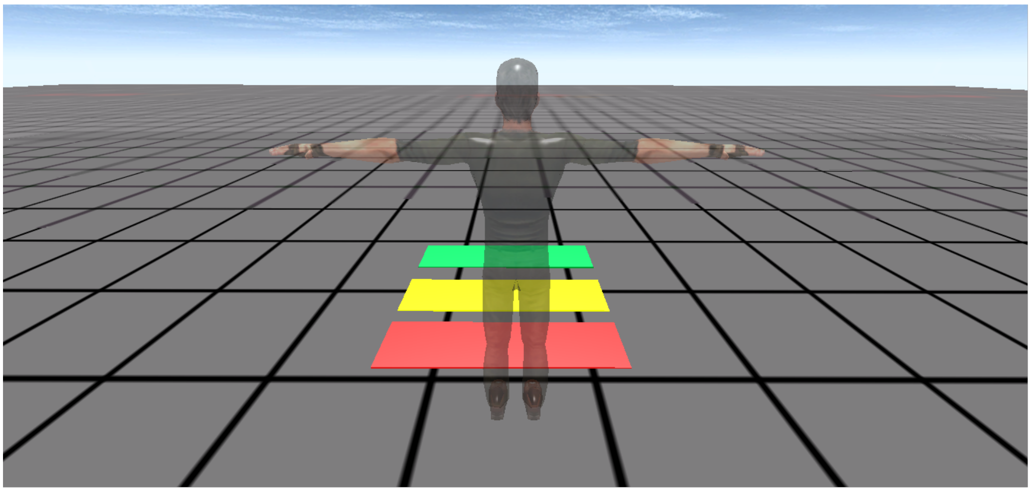


Figure 4: Starting conditions for Exercise #3.

2.2.2. Registration module This module is very important to perform monitoring, because it allows to save the studies and look up the medical records of the patients. At present, every patient has a register that includes the name, age, gender and pathology (the information could be increased if needed). Furthermore, each session linked to a particular patient is recorded using the session date, the exercise and its settings, the tracking data, the obtained results and additional comments about the session.

2.2.3. Core module This module includes the software functions related to the processing of the data collected from Kinect device during the exercises. The particularities are detailed next.

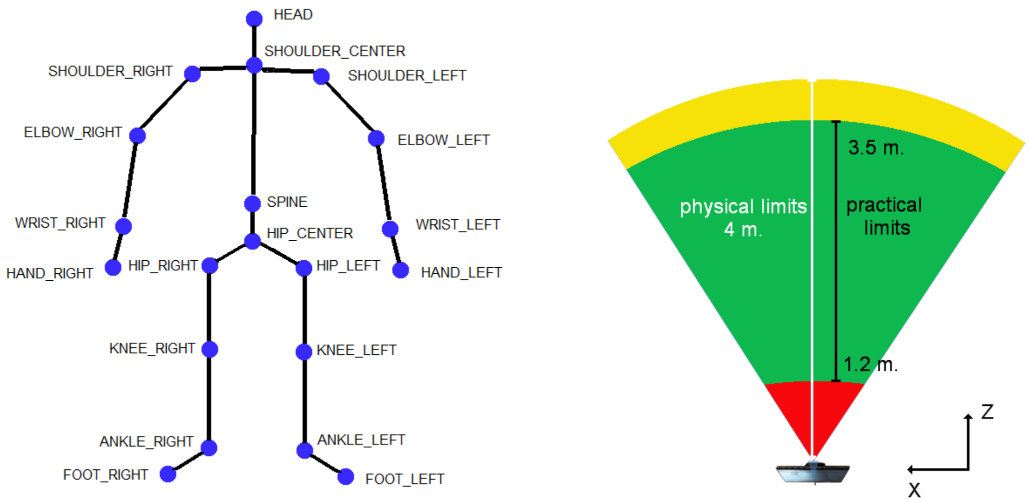
In Figure 5a, a human body with the tracking points is presented in order to simplify the references, and to attain a better understanding of the developed exercises. Due to the capabilities of the Kinect device, the user should respect the usability ranges (Figure 5b). Each exercise in our system has a validation step in order to suggest the user the best location in the room.

The system was developed in `C++`.The database was implemented using SQLite[1] because it is the most widely deployed database engine and its source code is in the public domain. In order to develop the *virtual sceneries*, the Unity3D[2] development platform was used. This is a flexible and powerful tool for creating multiplatform 3D applications and its integration with Kinect is achieved by a wrapper developed by Rumen Filkov [16]. The Kinect device provides the orientation information for the skeleton as hierarchical rotation matrices based on the bone relationship. This information is used by the wrapper to perform the animation.

3. System tests and results

In this Section, the results of the system evaluation in real conditions are presented. Three patients with different pathologies were invited to perform the exercises under the strict monitoring of the physiotherapist. Brief descriptions of the patients are shown in Table 1. It is important to mention that patients B and C have important motor problems. The patients were requested to perform two initial attempts before registering the data, in order to learn the functioning and become familiar with the system.

[1] https://www.sqlite.org/.
[2] https://unity3d.com/.



(a) Tracking point in a human body. (b) Usability ranges for Kinect device.

Figure 5: (a) Tracked points and (b) general specifications for Kinect working conditions.

Table 1: Brief descriptions of patients.

Description	Gender	Age	Pathology
Patient A	Female	18	Brain tumor
Patient B	Female	38	Cerebrovascular accident
Patient C	Male	20	Dystrophy

3.1. Results of Exercise #1
For this exercise, the inclination angle was set in 12°, 24° and 36° for both sides and the number of repetitions was fixed to 10. Figure 6 shows the patients performances in time (sampling rate is 1/30 seconds). The red line represents the goal angles and the blue line is the reached angle. Positive angles represents inclinations towards left side and negative angles indicates inclinations towards right side.

As can be observed, patient "C" has many difficulties to accomplish the objective. The discrete scores computed for the exercise were: 8/10 for patient "A", 6/10 for patient "B" and 4/10 for patient "C".

3.2. Results of exercise #2
For this exercise, the parameters were fixed at: 20 cm for the level to which the foot should be raised up, 5 repetitions, the rigth foot as the starting foot (the superior balls take the opposite side of the lower balls).

Figure 7 presents the evolution of foot height in time (blue line), one foot per time alternately. The red line shows the threshold altitude. As can be seen, patient "A" has not problems to perform the exercise while the others patients cannot accomplish the objective in most cases. Patient "C" showed serious problems to raise the left leg up. The complete running of this performance can be seen at `https://youtu.be/-tt-3Cp1Nhw`.

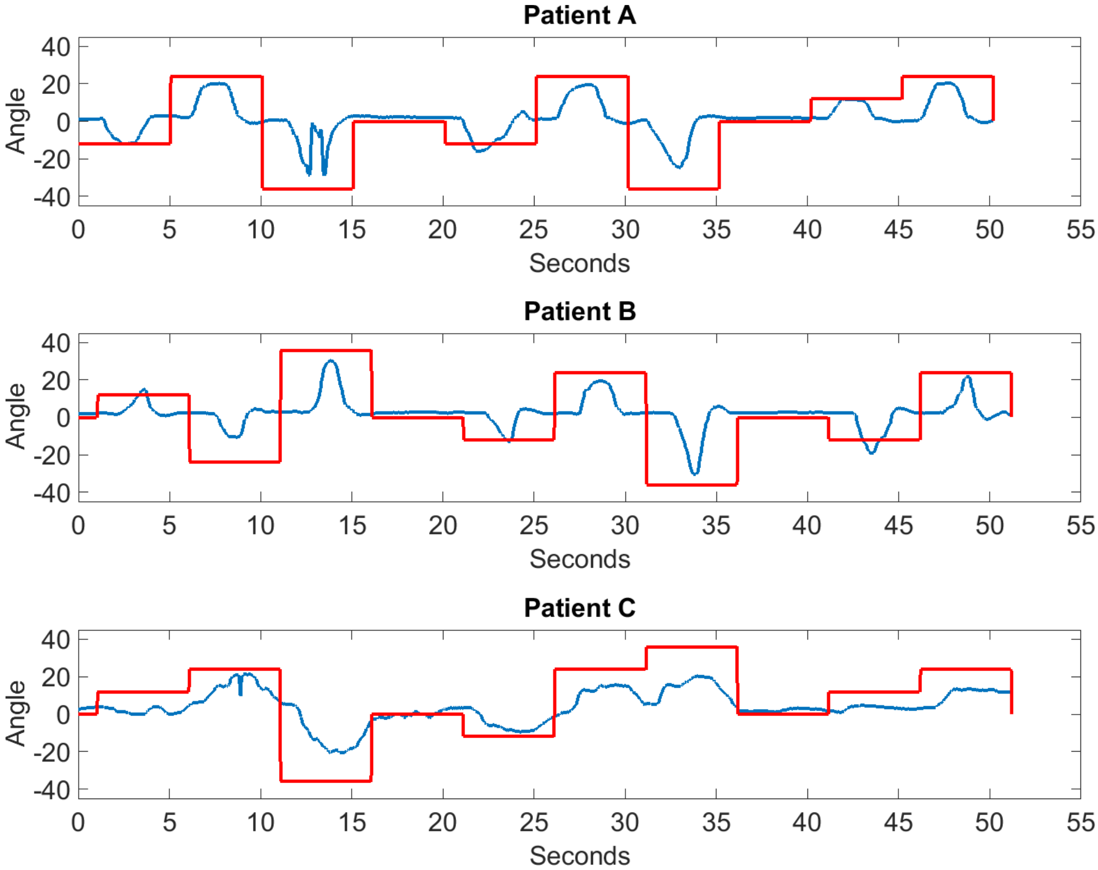


Figure 6: Results of Exercise #1.

3.3. Results of Exercise #3

Figure 8 exhibits the performance of patient "A" showing the traversed distance over time. The graph is presented as a user gait towards the Kinect device, within the usability ranges of Kinect. The green line shows the left foot trajectory while the red line represents the right foot. As can be seen, the patient started the exercise stand up at 3.7 metres from the camera. Using the collected information, the specialist can estimate the step length and speed, also they can check the sequence of the steps.

4. Conclusions and future work

In this paper, we have presented a system for rehabilitation of neurological patients using Kinect technology. A set of different routines were designed and developed according to requirements of expert physiotherapists.

Our system allows to collect data from movements during the exercises and save them in medical records. This information is very useful to evaluate the biomechanics of the patients and it allows subsequent and repetitive analyses, even in medical inter-consultation. Furthermore, the "games" were developed to be easily understandable and to provide information in order to assist the expert and user at every exercise. Preliminary results indicate that patients have a great predisposition and a notable interest to use the system. In addition, the specialists are favourably satisfied with the system performance and they consider very useful the monitoring data collected.

In future works, the amount and accuracy of the extracted data will be improved using arrays

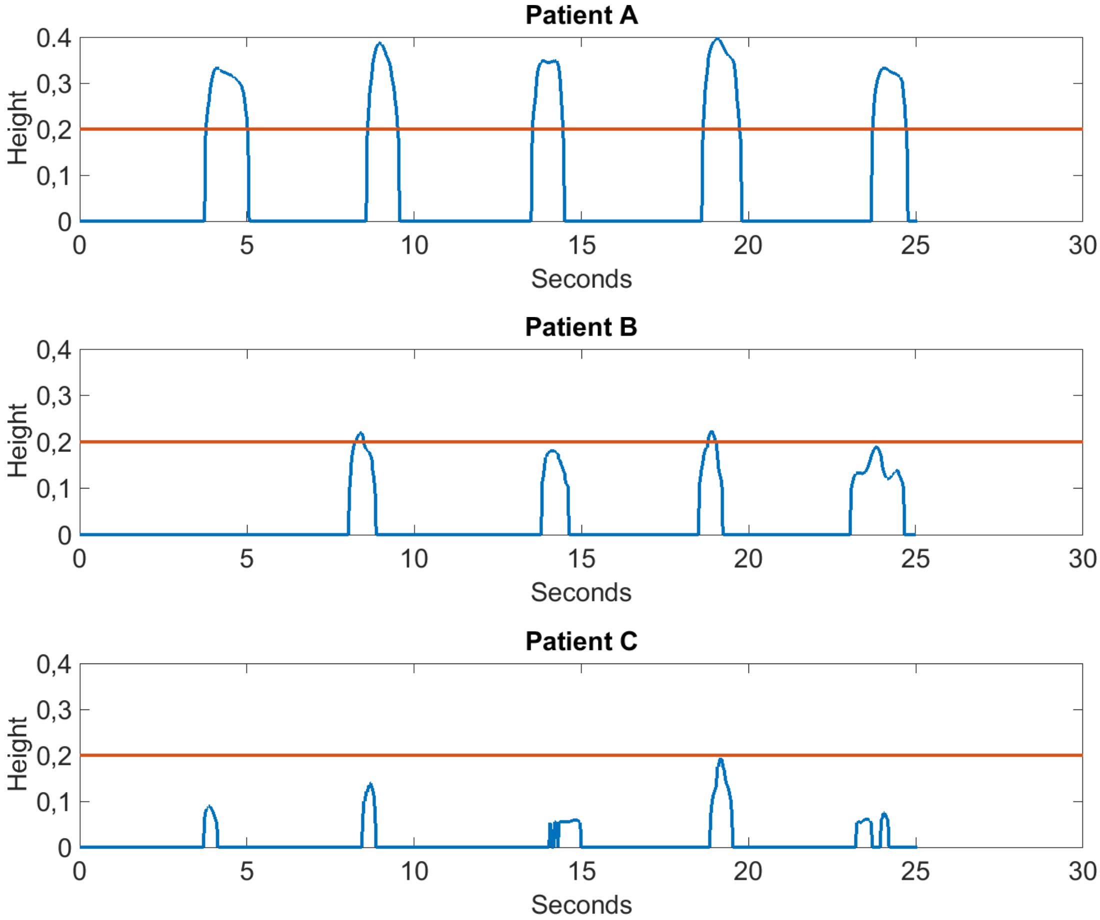


Figure 7: Results of Exercise #2 .

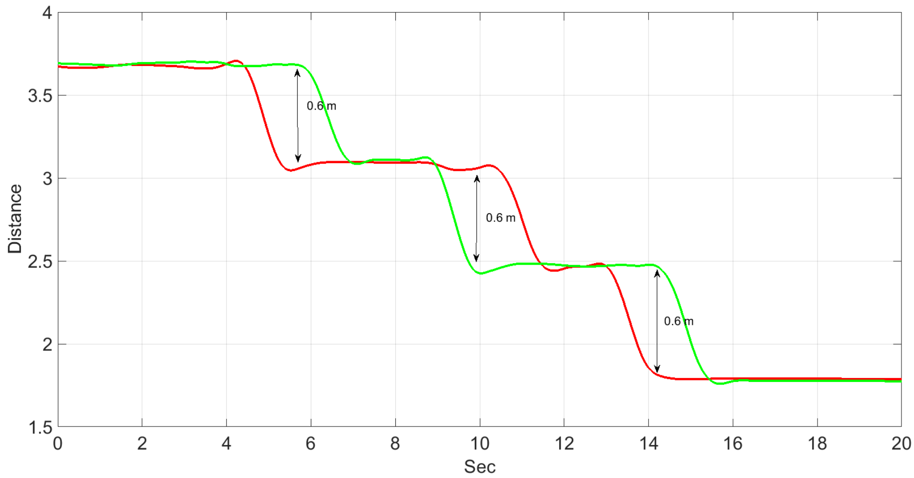


Figure 8: Results of Exercise #3 for patient "A".

of Kinect devices, which would make possible to extend the range of movement for Exercise #3. On the other hand, the actual system will be integrated with new technology as the Wii Balance Board. Furthermore, the management of medical records and its accessibility will be improved using intuitive graphical interfaces.

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