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USE OF AUGMENTED REALITY AND ARTIFICIAL INTELLIGENCE IN REHABILITATION

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Abstract: The regulation of telerehabilitation in Brazil, due to the Covid-19 pandemic, was made official by COFFITO Resolution No. However, in the absence of telerehabilitation facilitating devices, there is a need to develop tools that would enable the prescription, follow-up and monitoring of sessions. The objective of this work is to evaluate the system developed at the IFRJ that uses the Kinect device and its functionalities to monitor the execution of exercises prescribed by a professional physiotherapist or occupational therapist. The methodology used involves the construction of an exercise monitoring and prescription *software* by the multidisciplinary team (IFRJ Innovation) to work in the Teleconsultation and Telemonitoring system. A protocol was elaborated to standardize the correct execution of the movement and, later, tests were carried out to evaluate the system's ability to identify errors, comparing them to the established standard movement. The *software* was used *Make Human* and *Blender,* where it was possible to create an animated guide for the correct execution of the exercise. We opted for the "squatting" movement for the first phase of the program, with observation in an anterior view and identification of possible errors: dynamic knee valgus, anterior inclination (flexion) of the trunk and asymmetrical movements of the lower limbs. During the execution of the movement, the patient is monitored by the *Kinect* that supplies the data to an artificial intelligence network in order to obtain an instantaneous *feedback* of the correct or incorrect execution. Initial tests demonstrated that the *software* is capable of identifying the correct or wrong pattern of movements, but new exercises/protocols must be studied and tested in order to improve the system.

Keywords: augmented reality; rehabilitation; motion analysis; kinect

INTRODUCTION

New rehabilitation tools based on Virtual Reality (VR), Augmented Reality (AR) and video games are being developed and have recently sparked significant interest in the field of rehabilitation (POSTOLACHE et al, 2021). Recent studies show promising results in the use of tools that combine computer vision with artificial intelligence to help prescribe and evaluate the execution of exercises in the field of rehabilitation. In this sense, *software* can be used both in clinics and at home, where it is possible to maintain patient continuity in the rehabilitation program. Augmented reality is characterized by the use of three-dimensional technology, involving the patient's interaction with the virtual environment in situations that simulate real life. Admittedly, performing activities in a virtual environment stimulates multiple sensory channels, which are fundamental to the rehabilitation process (JERÔNIMO and LIMA, 2006; RIZZO, AA, BUCKWALTER, JG, NEUMANN, U., 1997; CHERNIACK EP, 2011). Virtual games, being more attractive, interesting and innovative, are capable of creating greater patient motivation, enabling better results (MA M., PROFFITT R., SKUBIC M., 2018).

In recent years, video games have become very popular all over the world, both for recreational and rehabilitation clients, where physiotherapists and occupational therapists have expanded their use in clinics, hospitals, homes, etc. (MA M., PROFFITT R., SKUBIC M., 2018; SCHAHAM et al, 2018). Popular examples of video game devices that can be used in this context include the Nintendo® Wii Remote, PlayStation Move (Sony®) and Microsoft® Kinect.

One of the ways of using technology in rehabilitation is through the Kinect, an innovative device developed in 2010 in which the players' body movements allow interaction with virtual games (MEDEIROS, 2011; SCHAHAM et al, 2018) (Figure 1). This device consists of a three-dimensional movement capture system, capable of identifying 25 joint centers in the human body through an RGB camera and a depth sensor that make it possible to track movements (SCHAHAM et al, 2018; ORAND et al., 2019). In addition to not requiring specific body markers, as in the "gold standard" multicamera system for movement analysis, it is portable, low cost and easy to configure, and can be used both in domestic environments and in clinics (CHANG et al, 2012; TIPTON et al, 2019).

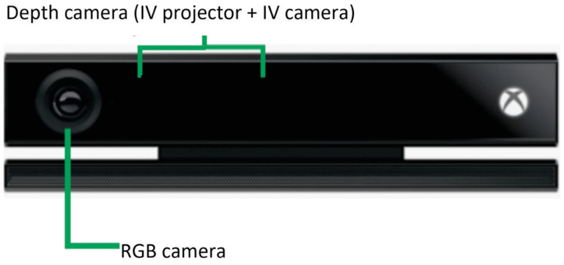


Figure 1: Kinect device and its InfraRed (IR) sensors used for image capture.

Due to the high cost associated with traditional rehabilitation, Kinect makes rehabilitation more affordable. Studies show its applicability in neurological rehabilitation, especially in patients with Parkinson's disease (GARCIA AGUNDEZ et al, 2019) and after cerebrovascular accident (CVA), with promising results, showing great therapeutic potential (SCHAHAM et al, 2018; ORAND et al, 2019).

The literature contains still inconclusive studies carried out with the use of these technologies in rehabilitation, especially with the Kinect. The authors used different software to analyze parameters related to movement and, in addition, the results are different when comparing upper and lower limbs, neurological and orthopedic patients, etc., and the correlation between Kinect and the 3D multicamera system is still unclear. is not well defined, requiring further studies.

In view of the current scenario, due to the COVID-19 pandemic, and the emergence of telerehabilitation, it is necessary to improve new approaches between therapist and patient. In this sense, new perspectives in rehabilitation and patient follow-up depend on the development of platforms and devices that allow remote monitoring, especially asynchronous monitoring. The work in question aims to meet this demand from society and propose solutions that can contribute to the inclusion of digital technologies as tools for monitoring patients in a motivating way, facilitating adherence to treatment in domestic environments, clinics and outpatient clinics.

GENERAL OBJECTIVE OF THE WORK

Evaluate the system developed at IFRJ that uses the Kinect device and its functionalities to monitor the execution of exercises prescribed by a professional physiotherapist or occupational therapist.

SPECIFIC OBJECTIVES

- Evaluate the system's ability to identify the correct pattern of a predetermined movement.
- Evaluate the system's ability to detect incorrect movements, making it possible to identify the type of error committed.
- Present a digital tool that encourages the patient to participate in physical rehabilitation sessions, with challenges and playful virtual scenarios;
- To present a system that allows the physiotherapist and occupational therapist to develop hit and miss patterns for the movements that will be performed by the patients with *feedback* in real time;

METHODOLOGY

The project was developed through a partnership between two IFRJ campuses: Campus Realengo and Campus Nilópolis. The design and execution team of the project is made up of professionals with different backgrounds: Physics, Computer Science, Physiotherapy and Occupational Therapy and scientific initiation students from the Physiotherapy and Physics Degree courses.

MATERIAL DESCRIPTION

The Kinect device is able to recognize the human body from the movements of the joints of the hips, knees, ankles, shoulders, elbows and wrists, in addition to recognizing the trunk and head (ORAND et al, 2019). This recognition can be done in the frontal and sagittal planes, in addition to the possibility of estimating the position of the limb based on the perception of the distance from the device.

Figure 2 shows an image where you can see the "skeleton" structure obtained using the kinect. In it, it is possible to see the representation of the "bones" and "joints" that will be used to build the desired software.

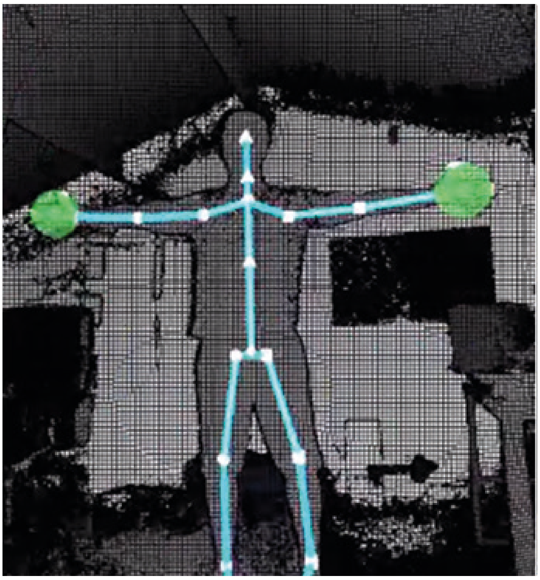


Figure 2: Image illustrating the “joints” and “bones” that are identifiable by the kinect. In the figure on the right, the user’s image, without filters.

STUDY OF MOVEMENTS

Among the several possible exercises to be monitored by the system, the “squatting” movement was chosen as the pilot for the project, with the observation being made in an anterior view with identification of possible errors: dynamic valgus of the knee, anterior inclination (flexion) of the trunk and asymmetric movements of the lower limbs. The Physiotherapy course students participating in the project carried out a bibliographical survey to establish the correct movement pattern and identify the main errors in the execution of the movement that could be observed in the anterior view by Kinect.

As a correct standard, the following aspects were established:

1. Foot placement: It is recommended that a moderate foot placement angle (approximately 20°) in combination with a moderate stance width (feet approximately shoulder-width apart) be used. (LORENZETTI, S., 2018)

2. Amplitude: it is recommended to squat down to the anterior point of pelvic retroversion and with the spine aligned (SANTOS, 2018). The greatest compression and shear forces in the squat occur precisely at angles close to 90 degrees of knee flexion, still observing a tendency for reduction in forces, as the range of knee flexion increases. (GIOVAAG, et al, 2016), therefore the conversion of eccentric to concentric contraction would generate lower compressive forces if performed at angles other than 90 degrees.

3. Knee Alignment: The knees must be in line with the toes throughout the squat movement without shifting the knee medially or laterally. (LORENZETTI, S., 2018)

Main errors pointed out in the literature and that can be observed in a previous view: (SANTOS, 2018; CZAPROWSKI, D.; BIERNAT, R.; KEDRA, A., 2012)

1. dynamic knee valgus
2. Exaggerated trunk flexion
3. Asymmetric weight distribution

SOFTWARE DEVELOPMENT

The construction of the program was done using a Node.js server, and data files from a program called “Kinect Gesture Builder ” which is one of the applications of “Kinect Studio” - created by Microsoft. The Kinect Gesture Builder allows developer physiotherapists to produce an exercise file that is an artificial intelligence file that will be used by Kinect, ie, each exercise is transformed into an AI that will validate the exercises performed. It is necessary to “train” the artificial intelligence to identify the images coming from the videos: this training consists of performing exercises in front of the Kinect, using the “Kinect Gesture” program Builder ”. This intelligence, after being trained, is able to determine how close the two executed movements are: training and execution.

This system was developed in such a way that the exercises are trained and entered into a database, with automatic propagation to all users of the system - as soon as the end user updates the system, these exercises are downloaded. The user interface is a browser (Chrome or Internet Explorer), where the image captured by the Kinect appears, a number (which indicates how well the exercise is being performed) and an "emoji", which is a visual feedback of how adequate is the realization. The system runs on Windows, not yet available for Mac. The figure below shows a screen capture of the system's use.

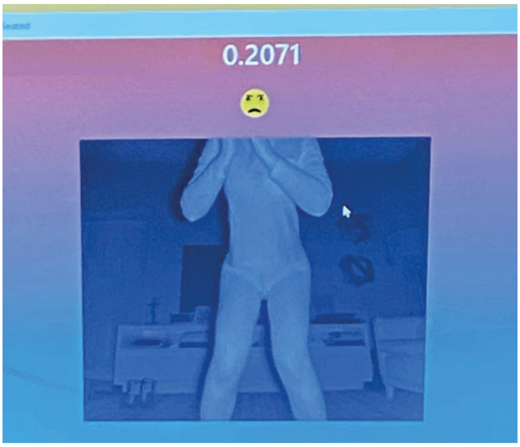


Figure 3 - Developed system running in an internet browser. The emoji appears in response to the user's deliberately wrong execution.

If there is interest in accessing specific joint movements - a function that is especially desired when the intention is to encourage the patient to perform a specific exercise - the group found the Unity software to be the most efficient solution: it must be adopted whenever there is interest in creating interaction between users with objects and scenarios. However, the use of Unity proved to be ineffective in the continuous monitoring of exercises, and must be adopted if the intention is to motivate the practice.

Figure 4 - Screenshot of using Unity to create a virtual environment that encourages the user to exercise. The character on the left of the figure is an avatar developed by the group that serves as a model.

TRAINING STUDENTS TO USE THE SOFTWARE

After finalizing the system prototype, the student developer recorded a tutorial indicating the step-by-step process for capturing motion and training the system to identify the correct pattern.

An infographic was also prepared to guide the stages of the process, which consisted of:

1 - Construction of the gesture: capturing the movement performed by the volunteer with a correct pattern and some incorrect movements. The generated file will be submitted to the training stage;

2 - Training: the physiotherapy students analyzed the movement performed by the volunteer and signaled in the system which movements would be correct or incorrect;

3 - Training/Analysis: The file generated from step 2 was compared with a new video captured with the same motion proposal as the previous one. Students observed whether the system, using the file generated in step 2, was able to identify the mistakes and successes of the new video.

4 - Training in real time: The volunteer performed the movement (correctly or incorrectly) in real time and the students observed whether the system properly signaled the errors and successes.

5 - Record of the built and trained movement and its inclusion in the system to be used by physiotherapists.

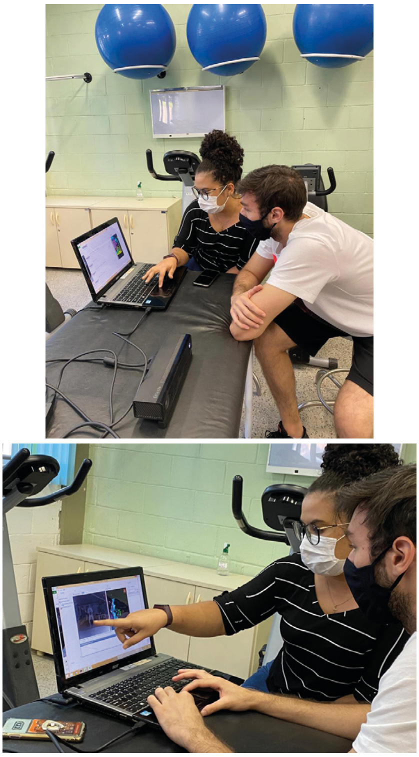


Figure 5 A - Students performing the construction of the gesture. B - Students performing the system training stage

TEST PROTOCOL

To carry out the tests, the volunteer was positioned in front of the *Kinect* device in the orthostatic posture, 2 meters away. The device was on a surface 75 cm from the ground.

The following gestures were built:

A) error-free squat movement;

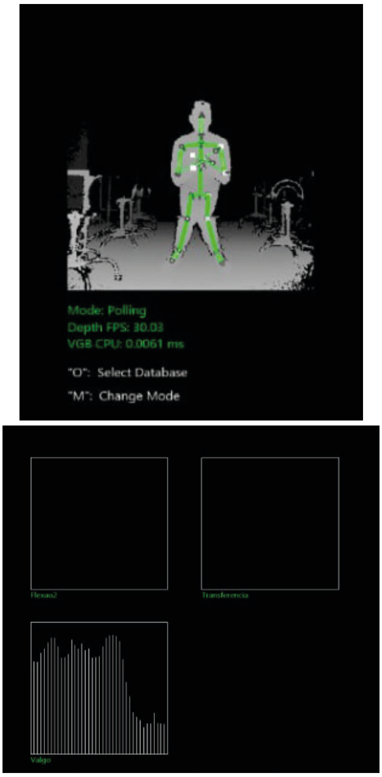
B) correct movement + dynamic valgus

C) correct movement + exaggerated trunk flexion

D) correct movement + lateral transfer of weight

Initially, the movements considered correct and the others as errors were marked during training. In a second stage of training, the wrong movements were marked as correct, to see if there was a difference in the system's ability to identify the error depending on how the system was trained.

The four files with extension "gbd" created each contained a different error and the screen curves therefore signaled the return of machine learning for each error. By checking the changes in the specific curve named with the name of the error, it was possible to identify, not only that an error was happening, but also what type of error it was. The following figure shows the process of training and verifying the adequacy of the movements according to the feedback from the artificial intelligence.



Mode: Polling
Depth FPS: 30.03
VGB CPU: 0.0061 ms

Figure 6 - Screenshot of training for recognition of dynamic knee valgus. The squares with vertical bars represent the compatibility between the movement performed and the one identified by the network.

Figure 6 illustrates the training process for the knee: it is necessary to train the system with errors so that they are well recognized. The frames with vertical bars represent the concordance between the movements "taught" to the neural network and the user's execution. At the time of the screenshot, the developer physiotherapist was training dynamic knee valgus.

RESULTS AND DISCUSSION

During the tests carried out, it was verified that the system is able to identify the type of error that was being executed, in addition to how wrong (or right) the movement was when compared to the pattern learned by the system. For this, it was necessary to teach the system the errors that needed to be identified. The developed system has, on purpose, a redundancy in the identification of errors: it looks for movements that differ from those that are trained as correct and tries to identify how close the exercise performed is to a movement registered as wrong. With this, in addition to pointing out when the movement was not performed exactly as it must, it was still possible to identify which error was committed. The protocol used was to train the network to recognize each error in a different file.

It was found that without explicit training of the network to identify errors, the system only recognizes errors committed on purpose and "exaggerated". In the first test stage, in which the network was trained to identify the correct pattern, it was possible to clearly identify the errors "dynamic knee valgus" and "exaggerated trunk flexion" while the "asymmetric weight transfer" was only signaled by the system when too exaggerated. In the second stage of testing, where the network was trained to specifically identify the "asymmetrical weight transfer" and "exaggerated trunk flexion" movements, these errors were easily observed, while the "dynamic knee valgus" was not identified.

KNIPPENBERG et al (2017), in a systematic review, concluded that Kinect is the most used among available commercial equipment, that the most common activities were performed in a virtual environment, that stroke was the most common disease among patients. and that rehabilitation programs for upper limbs outperformed those for lower limbs. MA M., PROFFITT R., SKUBIC M. (2018) simultaneously evaluated young subjects using two different systems: Microsoft Kinect and the Vicon camera system, the gold standard for this purpose, and concluded that the developed software allowed a better good correlation in general, but for some movements it was not satisfactory. TIPTON et al (2019) evaluated 20 healthy subjects during lower limb movements that could predict risk factors for anterior cruciate ligament injuries and concluded that Kinect demonstrated low correlation when compared to multicamera 3D evaluation (Vicon) during limb impact activities lower limbs and complex movements. Therefore, for high-level athletes, the authors suggest the multicamera system as a precise tool Vicon, which is the gold standard for evaluating lower limbs. MENTIPLAY et al (2018), evaluated the reliability and validation of the Kinect V2 in the evaluation of joint angles in the sagittal and coronal planes while performing various movements and concluded that the Kinect demonstrated good-excellent inter-session correlation for trunk, hip and knee during squat and jump tests. Rajkumar, A., 2021, reports that although Kinect has been used extensively for *exergames* and rehabilitation, range measurements from markerless motion capture devices do not have the ability to resolve motion in three planes for each joint. In the same study, the authors identified the limitations of Kinect : it does not offer reliable measurements in the sagittal plane;

does not correctly measure elbow flexion from a neutral position and cannot measure forearm pronation and supination; shoulder rotation is calculated from elbow vector information projected onto the transverse plane; calculation of shoulder internal and external rotation can only be performed with the elbow flexed at least 30 degrees.

The experimental results presented in the present study corroborate those presented in the references regarding the viability of using the kinect as an auxiliary tool in the process of rehabilitation/exercise performance. Despite the limitations presented by the system, we believe that the use of virtual and augmented reality must be explored as a tool to motivate patients' adherence to the rehabilitation process. Additionally, the system contributes to the formative dimension of the students involved in the exercise registration process, allowing them to have access to the technological tools and procedures that represent the state of the art in the area of student training.

FINAL CONSIDERATIONS

We present a system developed at IFRJ as a result of a partnership between different *campuses* of this institution. This system has an interesting potential for monitoring the performance of various physical therapy exercises. The current stage of development does not allow making it available for public use: additional tests must be carried out to verify the effectiveness of the system. We believe that, in addition to resulting in a viable technological product, the present project is an excellent way of illustrating how the interaction between different areas of knowledge - physics and physiotherapy - can, and must, interact, with the aim of providing students with new experiences within of their training areas.

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