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Use of RGB-D Camera for Analysis of Compensatory Trunk Movements in Upper Limbs Rehabilitation

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Abstract: Assistive robotics has been shown to be an important tool in the patient's rehabilitation process. One of the first steps in this process is to capture the movements performed by the patient to analyze the movement restrictions presented. The present work presents the development of a range of motion measurement system based on the position of the joints in the three-dimensional space of the upper limbs using the Kinect sensor. In addition, preliminary tests are presented to capture compensatory movements of the trunk, in order to investigate the feasibility of using this system as a tool to detect compensatory movements.

Resumo: A robótica assistiva tem se mostrado uma ferramenta importante no processo de reabilitação do paciente. Uma das primeiras etapas desse processo é capturar os movimentos realizados pelo paciente para analisar as restrições de movimento apresentadas. O presente trabalho apresenta o desenvolvimento de um sistema de medição de Amplitude de Movimento baseado na posição das articulações no espaço tridimensional dos membros superiores usando o sensor Kinect. Além disso, são apresentados testes preliminares para capturar movimentos compensatórios do tronco, com o objetivo de investigar a viabilidade do uso desse sistema como ferramenta para detectar movimentos compensatórios.

Keywords: assistive robotics; rehabilitation; stroke; physiotherapy; compensatory movements.

Palavras-chaves: robótica assistiva; reabilitação; AVC; fisioterapia; movimentos compensatórios.

1. INTRODUCTION

The recovery of functional use of the upper extremity in patients with hemiparesis has been a longstanding struggle for patients and therapists. After the stroke most patients have residual motor deficiencies in the upper limbs, leading to long-term limitations, which impacts on quality of life (Duret et al., 2015).

According to the Brazilian Society of Cerebrovascular Diseases, stroke is the disease that most kills Brazilians and it is the main cause of disability in the world. Around 70 % of people who suffer a stroke do not return to work and around 50 % of people are dependent on other people for basic daily tasks. Many stroke survivors experience complex neurological deficits that impair the quality of movement, resulting not only in motor problems but also in cognitive and behavioral problems (Blaszczyszyn et al., 2018). In addition, according to the World Stroke Organization these numbers tend to get worse as they predict that one in six people in the world will have stroke throughout their lives (SBDC, 2019).

In addition, there are several other reasons that cause the loss of movement of a person, making him need some kind of assistance, they are: stroke, arthrosis, traffic and work accidents (Kuczynski et al., 2017; Nunes et al., 2012). Such loss of movement also makes these people need help not only to recover their movements, but also to carry out their daily tasks.

The use of robots for rehabilitation began in the 90's (Barbosa Faria Gonçalves and Almeida Gonçalves Siqueira, 2013) and robot-assisted upper limb rehabilitation techniques have advanced rapidly in the past few decades (Van Delden et al., 2012; Brackenridge et al., 2016; Lo and Xie, 2012; Proietti et al., 2016). With respect to traditional rehabilitation interventions, robotic systems can provide more intensive physiotherapy with the implementation of several interactive strategies. The device can be a mechanic or a computer-controlled robot. These robotic systems allow practice with varying levels of assistance including active, passive and active assisted movement modes and these strategies can be adaptively adjusted on a computer

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depending on the individual's disability level (Miao et al., 2018).

Being that, optical motion capture is a powerful tool for assessing upper body kinematics including compensatory movements in different populations. (Reiss, 2007) introduces the concept of structured light systems. According to the author, structured light is a light emitted by a source and whose propagation is modified to acquire a specific shape when projected on a surface. The objective of structured light reconstruction techniques is to measure the shape of three-dimensional objects using automatic techniques, without contact with the observed object (Robinson et al., 2004).

Alternatives for obtaining the range of motion developed by the patient's joints are extremely important, since it is currently performed by traditional equipment such as the goniometer which, in some applications, is inconvenient and sometimes unreliable (Lee et al., 2015). There are some low cost sensors on the market that use the structured light reconstruction principle. PrimeSense is an Israeli company that became known for developing the technology used in Microsoft's Kinect sensor, which will be used for the development of this work.

In view of this, the Assistive Robotics (AR) group at the Federal University of Rio Grande (FURG) seeks to develop tools in the areas of robotics, computing and automation for assistive rehabilitation. This work arises with the objective of developing a Range of Motion (ROM) measurement system based on the position of the joints in the three-dimensional space of the upper limbs using the Kinect sensor and, furthermore, with the objective of accomplish analysis of compensatory movements performed by the trunk of the patients.

2. RELATED WORKS

During the rehabilitation training process, patients tend to compensate for the compromised upper limb by recruiting intact trunk muscles and joints Cirstea and Levin (2000). This compensatory movement is called trunk compensation.

Within the various compensatory movements that can be performed, the movement of the trunk, even though it is not frequently addressed in analyzes of upper limbs of non-disabled individuals, has a very important evaluation when it is desired to study the upper limb impairments Valevicius et al. (2019).

Initially, the idea was basically to physically restrict Michaelsen et al. (2001); Michaelsen and Levin (2004); Pain et al. (2015); Greisberger et al. (2016); Bakhti et al. (2017) to the movement of the trunk of stroke patients. This physical restriction of the patient's trunk in the chair happened through straps, in order to avoid the removal of the trunk from the chair and, consequently, the movement compensation. Thus, it can be concluded that at this first moment, such limitations were able to improve the function of the patient's arm.

However, the rehabilitation process for mainly post-stroke patients is intense and repetitive, causing long-term physical restrictions to cause discomfort and anxiety. Thus, solutions that did not use physical restrictions began to gain greater focus in this area, such as the use of wearable inertial sensors or cameras.

The wearable inertial sensors were initially intended only to assess and monitor the motor capacity of the upper limb in stroke patients, but studies have advanced and showed that they could also be used to detect compensatory movements Ranganathan et al. (2017); Najafi et al. (2003); Salazar et al. (2014).

The use of cameras has gained greater popularity than wearable inertial sensors Duff et al. (2010); Subramanian et al. (2013), since it is not necessary to fix any object on the patient's body, making the method less invasive. Several studies Nordin et al. (2016); Lin et al. (2019); Bakhti et al. (2018); Zhi et al. (2017); Taati et al. (2012) have been carried out in order to improve a series of aspects related to the use of cameras to detect compensatory movements in order to assist in the limb rehabilitation process higher.

An important step in the movement rehabilitation process is the assessment of movement limitations. Goniometric measurements are used by physiotherapists to quantify movement limitations, choose appropriate therapeutic treatments and documnt the patient's evolution. For Gajdosik and Bohannon (1987) the evaluation procedure with a goniometer can be considered a fundamental part of the "basic science" of physiotherapy. The diversity of ROM capture methods is also highlighted, from a simple visual estimate to high-speed cinematography, however, among the different methods, the most commonly used is the goniometer.

In Krishnan et al. (2019) they carried out a study and presented a survey of the functional kinematic representations of the human shoulder, according to the authors the shoulder is an important functional articulation and its great range of movement brings several challenges. This joint is responsible for a large part of the movements of the arms and, therefore, the diagnosis of possible restrictions of the patient becomes complex. Figure 1 shows the eight assessments necessary for all shoulder movements to be diagnosed. The study also highlights the challenges in analyzing this joint such as complexity, inconsistent clinical description as to the current movements of the joint, measurement limitations, movement variation, among others.

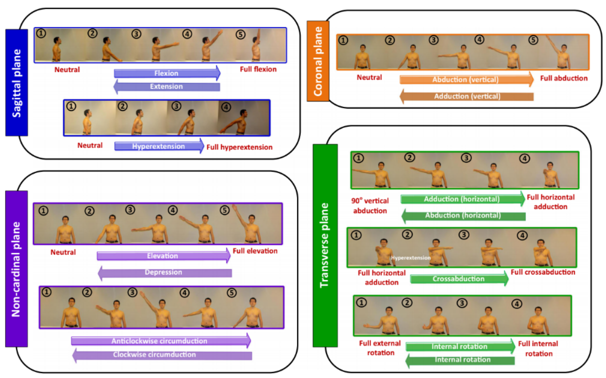


Figure 1. Shoulder assessments (Krishnan et al., 2019)

A proposal for using Kinect to assess the rehabilitation process was presented in Neto et al. (2018), called GoNet v2. Tests were carried out on volunteers, and six joints of the upper limbs of each person were analyzed. The interface created is able to show the professional all the patient's joints and select the range of motion analysis to be performed on. In addition, this software is also able to identify the professional who is performing the procedure as well as the patient and store this data in a database for analyzing treatment progress. To validate the results, a comparison was made between the readings performed by the proposed system and a traditional evaluation using a goniometer. The results of the comparison were considered very satisfactory by the authors in most movements performed by the joints, except for ulnar and radial deviation, which obtained a greater error. For the evaluation of the system, a questionnaire was also carried out with the professionals who used the tool regarding the impact of its use, which also generated a positive result.

3. METHODOLOGY

It is known that it is necessary to perform a reading and capture the movements performed by the patients in a reliable way. Thus, it was decided to use the Microsoft Kinect v2 sensor, presented by Figure 2, the sensor was chosen because it meets some characteristics intended in the project, such as low cost. This sensor has the SDK Kinect for Windows 2.0 library, which previously has all the points captured by the sensor, these points are presented by Figure 3. Thus, using this library and some modifications / adaptations, Kinect v2 can be used as the sensor for capturing compensatory movements.

Figure 2. Microsoft Kinect v2 sensor

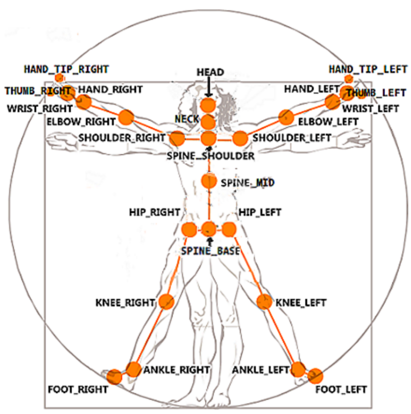


Figure 3. Kinect v2 capture points

Another important issue in relation to Kinect is that from the information obtained from reading the movements, it is possible to obtain graphs in relation to time so that it can analyze and compare the behaviors of the movements in different patients and/or volunteers. The software interface used to capture the movements is shown in Figure 4. In the proposed system the patient is positioned approximately 2 meters away from the sensor, in a closed environment and without obstructions of vision. The points of interest in this work are the shoulders and elbows of both arms..

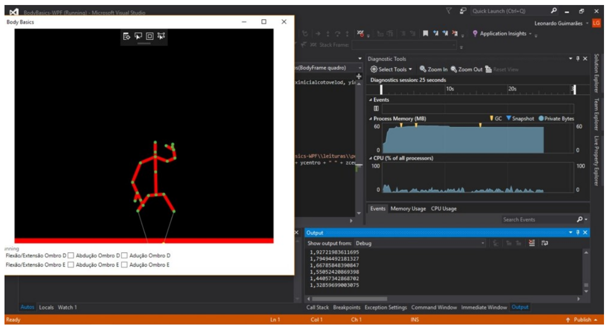
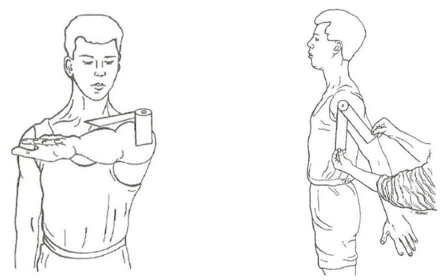


Figure 4. Software interface used for capture via Kinect v2

Therefore, for a better understanding of the behavior of the developed software, it was decided to analyze two different movements, based on two different analyzes, which will be explained later in the Tests and Results section. The movements analyzed were extension and adduction, presented by Figure 5.



(a) Extension movement

(b) Horizontal adduction movement

Figure 5. Example of horizontal extension and adduction movements (Marques, 2003)

4. TESTS AND RESULTS

The tests were separated into two groups: the first one aims at presenting the range of motion capture tests, in order to test the software and the methodology being developed. On the other hand, the second group of tests aims to test the methodology for reading the compensatory movements, so that one can analyze the existence of these movements for further advances related to this work. It is worth mentioning that, in order to facilitate the study and analysis of the functioning of the methodology, it was decided to use the same movements in both tests, as described in the methodology previously. The results are being captured and analyzed together with students and teachers of the physiotherapy course at Anhanguera College of Rio Grande.

4.1 Range of motion capture tests

The tests carried out occurred by comparing the system developed with the tests traditionally performed, with the use of a goniometer. In these tests 9 volunteers, students of the physiotherapy course, act as patients, performing the proposed movements and as professionals, performing the appropriate measurements. In this way, it is possible to remove information such as the mean and standard deviation of the measurements taken. As for the system with Kinect, each volunteer performs the movement 10 times so that there is also information such as the average and standard deviation of the readings performed.

The first movement analyzed was adduction. Figure 6 shows the results obtained for this movement, in the graph information about mean values and standard deviation (vertical axis) of measurements is presented through Kinect (blue) and through goniometry (red) for each individual (horizontal axis). The average standard deviation of the Kinect was approximately 3.6 °, already through the goniometer an average value of approximately 3.24 ° was found, which shows a more dispersed Kinect result compared to traditional goniometry, but close. Table 1 shows in more detail the data present in the graph.

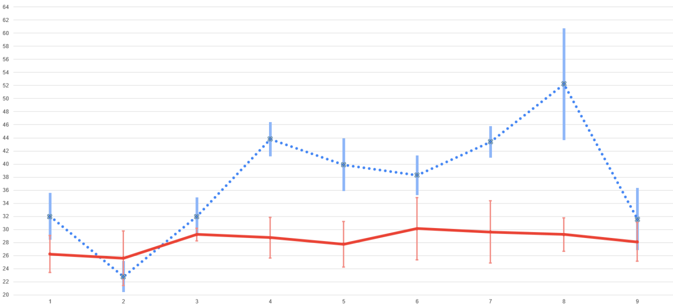


Figure 6. Comparison of the results obtained for the adduction movement through the Kinect and goniometer. The dotted line represents the mean and standard deviation obtained through the Kinect, while the continuous line represents the mean and standard deviation obtained through the goniometer.

x	Kinect Avg	Kinect Std Dev	Goniometer Avg	Goniometer Std Dev	Error
1	32	3.3763288603	26.25	2.817356917	-5.75
2	22.8	2.181742423	25.625	3.849198167	2.825
3	32	2.683281573	29.25	1.030157507	-2.75
4	43.8	2.4	28.75	3.282607227	-15.05
5	39.9	3.806573262	27.75	3.410667539	-12.15
6	38.3	2.83019434	30.125	4.440077129	-8.175
7	43.4	2.2	29.625	5.095015571	-13.775
8	52.2	8.340263785	29.25	2.099562637	-22.95
9	31.6	4.543126677	28.125	3.149343955	-3.475

Table 1. Data obtained through traditional goniometry and Kinect for the right shoulder adduction movement.

The second movement analyzed was extension. Figure 7 shows the results obtained, the graph shows the values of mean and standard deviation (vertical axis) of the measurements through the Kinect (blue) and through goniometry (red) for each individual (horizontal axis). The average standard deviation found for Kinect was approximately 3.08 ° and for goniometry it was approximately 4.6 °, which shows a greater concentration of results using the proposed system. Table 2 shows in more detail the data present in the graph.

4.2 Trunk compensation tests

As previously stated, the tests carried out included 4 volunteers who did not have any type of movement restriction,

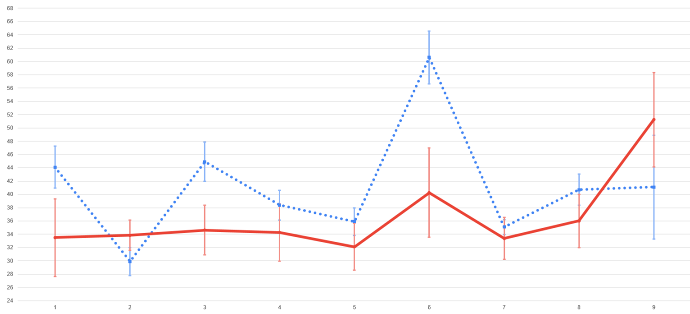


Figure 7. Comparison of the results obtained for the extension movement through the Kinect and goniometer. The dotted line represents the mean and standard deviation obtained through the Kinect, while the continuous line represents the mean and standard deviation obtained through the goniometer.

x	Kinect Avg	Kinect Std Dev	Goniometer Avg	Goniometer Std Dev	Error
1	44.1	3.144837039	33.5	5.830951895	-10.6
2	29.9	2.11896201	33.85714286	2.426703296	3.957142857
3	44.9	2.947880595	34.625	3.534090536	-10.275
4	38.4	2.244994432	34.28571429	4.633812925	-4.114285714
5	35.9	2.071231518	32.125	3.658928136	-3.775
6	60.6	3.954743987	40.25	7.18558648	-20.35
7	35.1	1.135781669	33.375	3.090472522	-1.725
8	40.7	2.32594067	36	3.922722919	-4.7
9	41.1	7.80320447	51.25	7.139999428	10.15

Table 2. Data obtained through traditional goniometry and Kinect for the right shoulder extension movement.

2 of whom were male and 2 female. Each of the volunteers performed each of the proposed movements, so that at the end of the tests there was a total of 4 measurements for each of the 4 movements selected. The test procedure and the results obtained for two movements will be presented separately below.

It is worth mentioning before presenting the tests themselves that for all of them it was decided to calculate the difference between points Shoulder_Right and Shoulder_Left provided by the Kinect© v2 library itself (presented previously by Figure 3).

Horizontal Adduction Movement The first test performed consisted of replicating the horizontal adduction movement, previously presented by Figure ref figure12a. It is a movement of the shoulder that allows an angular variation of a maximum of 40 °.

This test was performed twice by each volunteer: the first time the volunteers were free to perform the movement; while the second time they had a retention in the trunk, so that they could not use it to assist in the execution of the movement.

Figure 8 shows the results obtained with each of the volunteers analyzed, where the dashed line represents the result obtained with the free trunk and the continuous line the result obtained with the restricted trunk. From the graphs presented, it can be seen that the range of motion is greater when the volunteers are without any type of restriction on the trunk, this is because they use the trunk at the time of the movement, compensating the movement inappropriately, causing an unwanted movement. In contrast, when the volunteers have restricted trunk movement, the range of motion is much smaller and, consequently, the difference in trunk movement is much smaller as well, as volunteers are prevented from compensating for movement with the trunk.

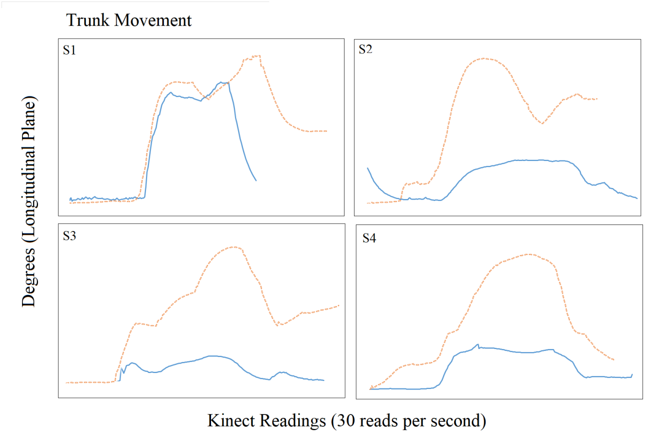


Figure 8. Graphs of trunk movement with and without movement restriction when performing adduction movement

Extension Movement The second test consisted of executing the extension movement, shown by Figure 5b. Consists, like the previous test, of a shoulder movement that allows an angular variation of at most 45°.

As in the previous test, it was performed twice by each of the volunteers. The first time the volunteers were free to carry out the movement, while the second time they had the trunk contained.

Figure 9 shows the results obtained with each of the analyzed volunteers. The logic of the graph is the same as the previous one, where the dashed line represents the result obtained with the free trunk and the continuous line the result obtained with the restricted trunk.

Figure 9. Graphs of trunk movement with and without movement restriction in the execution of the extension movement

Analyzing the graphs, it can be seen that for the extension movement the range of motion is also greater when the volunteers are without any type of restriction on the trunk, since as in the previous case, they use the trunk to compensate improperly the movement.

5. CONCLUSION

This is work in progress in the data capture phase, so the results presented are partial. However, it is possible to visualize, based on these results, the Capability of Range of Motion capture in an alternative way to traditional techniques. Improvements are still needed and are being studied, such as the use of two Kinect sensors in order to improve the visualization of joints in space, aiming to reduce hidden or overlapping points. An alternative with the use of two sensors is being studied in order to have a better result regarding the lesser overlap of points in relation to the camera.

Regarding the analysis of compensatory movements, it can be concluded that the results are preliminary, but they could show that it is feasible to use such a system to analyze compensatory movements. Other analyzes and improvements need to be made, but these preliminary tests were able to prove the applicability of the system developed for this type of movement.

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