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Dynamic Evaluation and Treatment of the Movement Amplitude Using Kinect Sensor

JOEL S. DA CUNHA NETO[1], PEDRO P. REBOUÇAS FILHO[2], GUILHERME P. FERREIRA DA SILVA[3], NATÁLIA B. DA CUNHA OLEGARIO[3], JOÃO BATISTA F. DUARTE[1], AND VICTOR HUGO C. DE ALBUQUERQUE[1], (Member, IEEE)

[1]Programa de Pós-Graduação em Informática Aplicada, Universidade de Fortaleza, Fortaleza 60811-905, Brazil
[2]Laboratório de Processamento de Imagens e Simulação Computacional, Instituto Federal de Educação, Ciencia e Tecnologia do Ceará, Limoeiro do Norte 62930-000, Brazil
[3]Núcleo de Pesquisa do Centro de Ciências da Saúde, Universidade de Fortaleza, Fortaleza 60811-905, Brazil

Corresponding author: Victor Hugo C. de Albuquerque (victor.albuquerque@unifor.br)

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ABSTRACT This paper presents a hybrid solution (software and hardware) integrating the computer and the Kinect sensor. The proposed solution, named GoNet v2, is an instrument for the dynamic and automatic evaluation of biomechanical rehabilitation processes. Experimental tests to evaluate the range of motion of body joints, especially for elbow flexion, elbow extension, shoulder abduction, shoulder flexion, radial deviation, and ulnar deviation, are presented and discussed. We also presented the exergamers for rehabilitation tests, based on Kabat diagonal and squatting. Ten healthy individuals were evaluated using the GoNet v2 and the universal goniometer, and twelve professionals evaluated the instrument through a survey. The intraclass correlation coefficient (ICC) was used to analyze the reproducibility, and for the accuracy analysis the errors were compared using the mean of the worst cases with movement. Regarding intra-examiner and inter-examiner reproducibility, high ICC values were found for the range of flexion/extension of the shoulder, abduction of the shoulder, and ulnar deviation, thus showing its optimum precision. According to the evaluation of the specialists, the GoNet v2 gave better results for the flexion/extension of the shoulder (3.61%) and elbow (3.17%), and also the abduction (2.11%) of the shoulder compared with the goniometer. The results showed that the GoNet v2 had a high reproducibility, except for radial deviation. The accuracy results were good for the abduction measurements of the shoulder and the flexion/extension measurements of the elbow and shoulder.

INDEX TERMS Arthrometry, biomechanical rehabilitation, exergames, Kinect sensor, dynamic evaluation, goniometry.

I. INTRODUCTION

Technology has become one of the greatest allies in providing benefits to specialists in various fields, such as in health, and consequently helping patients through the use of alternative and/or complementary computational tools to the conventional treatments. Among other benefits these tools are able to elaborate diagnoses faster and more accurately than specialists, thereby reducing subjectivity in the interpretation of the exams. Also these tools can be used to develop games dedicated to the treatment of motor and cognitive rehabilitation of patients.

The need to develop intelligent biomedical systems for different scenarios is continually increasing and consequently numerous solutions arise to cater for these challenges. Biomedical Engineering has developed a large number of computational tools and sensors capable of accurately aiding in the elaboration of diagnoses, such as electroencephalogram (EEG) signal classifications for the diagnosis of epilepsy [1], a low-cost postural monitoring system based on accelerometers for patients with stroke sequelae [2], cardiac arithmetic classifications [3], a computer-aided rehabilitation system for patients with AVC sequelae [4], a new radial active contour method (ACM) applied in the segmentation of the left ventricle from echocardiographic images [5], assistance for people with attention deficit and hyperactivity by reducing hyperactive behavior using an air mouse in a controlled stimulation environment [6], ACM balloon adaptation for lung segmentation [7], increased virtual reality for rehabilitation of stroke patients [8], hospital automation [9], robotic prostheses of one leg that is controlled by electromyographic signals [10], segmentation and reconstruction of pulmonary structures from computed tomography images of the thorax [11], [12], rehabilitation of children with cerebral palsy through a virtual environment [13], among many other uncountable applications.

Recently, several instruments have been developed for the evaluation of range of motion, ranging from simple tools, such as the universal goniometer, to electromagnetic computerized kinematic analysis systems [14] or computerized photogrammetry [15]. However, in general, such equipment is extremely complex has a high commercial cost, a specific use, and is therefore not very accessible for clinical practice [16]–[18].

During rehabilitation sessions, patients need to make specific movements for their therapy to take effect. The use of serious games, coupled with rehabilitation, can increase the motivation of patients to accomplish the treatment, as well as improve the correctness index of their own movements [19]–[27].

In order to map and monitor human body movements in real time, tracking and storage systems using cameras are necessary, and the the individual in question is required to wear uncomfortable markers or suits. Currently, research focuses on estimating specific human postures without the use of markers [28], [29]. However, even if multiple cameras are used, this task poses a challenge because of the complexity of human movements and their extremely variable appearance in images that are furthermore sensitive to illumination and occlusion [30], [31].

Physiotherapy can be defined as the science applied to the study, diagnosis, prevention and treatment of kinetic dysfunctions of organs and systems. Physiotherapy applies procedures, techniques, methodologies and specific approaches that aim to evaluate, treat, minimize problems, prevent and cure a large varied of dysfunctions [32].

A goniometer is a commonly used tool to measure range of motion (ROM) of body joints. It is used to follow up the clinical evolution of a patient in recovery, and it measures angulations in relation to a reference, such as the arm in relation to the trunk The goniometer consists of two translucent arms with markings from 0 to 360°. In the literature it is considered as a ‘‘gold standard’’, in which its results must be compared with other manual instruments used in joint measurements [33].

The current method to measure range of motion body joints requires the wearing of equipment, and is subject to parallax errors and human errors during the angle measurements with the device, as well as being quite expensive for the specialist. Furthermore, it is a static examination, in which the patient needs to remain still in a certain position, for an indefinite period, so the professional can carry out all the necessary measurements.

In order to overcome such difficulties, we developed an alternative and complementary tool that is capable of assisting specialists in treatments and dynamic assessments of the range of motion of body joints. This tool is able to obtain results quickly and accurately, store the measurements on a database and generate graphs related to the progress of the rehabilitation at different stages of the therapy. Such data can reduce errors in the evaluation and help professionals to analyze the results of the patients as well as verify the evolution of their clinical picture. Finally, a statistical validation and questionnaire was given to the specialists who then validated the proposed system.

This work presents the development of a hybrid solution (software and hardware) integrating the computer and the Kinect sensor. The proposed solution, named GoNet v2, is an instrument for the dynamic and automatic evaluation of biomechanical rehabilitation processes.

II. METHODOLOGY

In this chapter, we present the experimental, computational and mathematical procedures used to measure the range of motion of patients/individuals in real time, as well as a new approach to treat patients with motor problems.

A. KINECT MOTION SENSOR

The Kinect sensor can, among other applications, be used to analyze and process body movements in real time, which is the main reason for its use in this work. In order to make the development of the proposed system less costly, an open source Software Development Kit (SDK) was used, since it allows the development, through libraries and preprogrammed examples of systems for different applications using C++, C# and the Visual Basic programming languages by adopting Microsoft Visual Studio 2010 or higher [34]. In addition, it allows direct access to real-time information from one or more Kinect, since the integration with the SDK is quite reliable as its developer has the same sensor and is constantly updating with new libraries and functionalities.

The SDK can detect up to 25 joints per person and a single Kinect recognizes up to six people, so with this SDK a single Kinect can detect and store up to 150 joints in real time. However, only 17 joints corresponding to the evaluation and treatment of the upper limbs were considered in this work, as shown in Figure 1.

The SDK does not require initial calibration by the operator since it compares images captured from the Kinect sensor with a pre-defined human model. Thus it quickly determines the regions and joints of the human body, enabling the processing of the desired information. Another factor when using this SDK is related to its predictive detection of joints, making the system less tolerant of mistakes compared to other SDKs. This is a great advantage in situations where information about the patient is lost, such as simulation of hidden limbs. However, the SDK here is used exclusively with the Kinect using the Windows operating system.

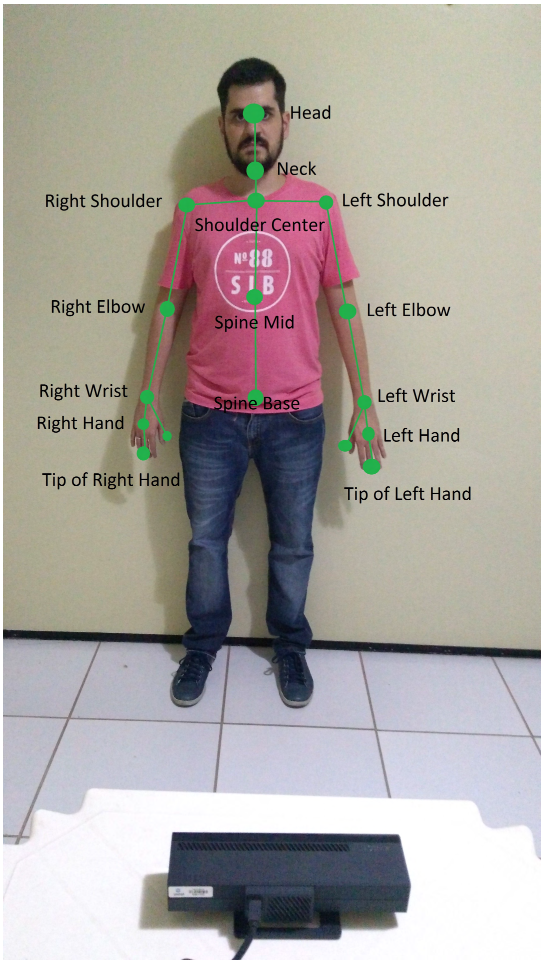


FIGURE 1. Correlation between the points generated by the Kinect sensor and the human body.

B. PROCEDURES FOR DATA COLLECTION

A total of 10 healthy individuals were used to evaluate the GoNet v2 (goniometry based on the Kinect sensor, version 2) and six exams were carried out: elbow flexion, elbow extension, shoulder abduction, shoulder flexion, radial and ulnar deviation, as described below.

In order that the whole body can be fully recognized by the sensor and can be seen on the interface screen the subject should be at least 2 meters (+0.5 meters) away from the Kinect sensor for all the proposed examinations. The sensor should be at a height of up to 1 meter.

The comparison between the GoNet v2 and the goniometer (gold standard), was carried out with both instruments with the subject standing at 90°. Initially, the subject, who had been trained to perform the proper movements for each examination, was positioned at a distance of two and a half meters from the Kinect, which stood at a height of 80 cm off the ground,. For the flexion and abduction exams of the shoulder and flexion/extension of the elbow, the individual was instructed to perform the movement until he/she reached the 90° angle according to the GoNet system and then maintain this position while the angulation was measured with the goniometer. Thus the GoNet measurement was a dynamic measurement and that of the goniometer was a static measurement.

In the repeatability evaluation, a fixed shield positioned at a height of 1.26 m was drawn to determine the range of motion to be performed for the flexion and abduction of the shoulder and flexion/extension of the elbow of the individual. In the ulnar and radial deviation tests, free movements were performed, respecting the maximum range of motion in both cases.

After recording the points for the desired joints, the angles are calculated, considering the x, y and z coordinates for each joint, in which the x and y coordinates correspond to the position of the joint in relation to the total field of vision of the Kinect and the coordinate z is the depth of field (distance from the joint to the Kinect). Once the coordinates have been defined, the vector between the points can be calculated by subtracting them.

Each vector corresponds to a part of a member. The whole virtual skeleton of the individual can be vectorized, and then the angle between the vectors ($\vec{u}$ and $\vec{v}$) can be measured by dividing the scalar product by the vector product (Equation 1).

$$cos\ \Theta = \frac{\vec{u}.\vec{v}}{|\vec{u}|\ |\vec{v}|} \tag{1}$$

The calculation of angle Θ and the formula with the expanded scalar and vector products are given by

$$\vec{u} = (X_1, Y_1) \tag{2}$$
$$\vec{v} = (X_2, Y_2) \tag{3}$$

All of this information is used to determine the range of motion of each exam, and is detailed in the next section.

1) FLEXION AND EXTENSION OF ELBOW

After the subject is recognized by the Kinect sensor (see Figure 1), he/she must rotate 90° to the left or right, so that the limb selected for the exam is facing the sensor. The subject should then, with or without the aid of the physiotherapist, perform the flexion or extension movement of the elbow. The flexion corresponds to the act of bending the arm and extension corresponds to stretching it. An illustration of this movement of the left limb is shown in Figure 2.

The spatial coordinates (x, y) of each of the three joints (shoulder, elbow and wrist) of the subject are needed to measure the angles corresponding to the elbow flexion and extension examination. The coordinates of the wrist, elbow, and shoulder were named (P_x, P_y), (C_x, C_y) and (O_x, O_y) respectively, as shown in Figure 3.

After obtaining the values of the coordinates, the vectorization of the limbs is carried out, resulting in 2 vectors referring to the forearm and biceps:

$$forearm(x, y) = (P_x - C_x, P_y - C_y) \tag{4}$$

and

$$biceps(x, y) = (O_x - C_x, O_y - C_y) \tag{5}$$

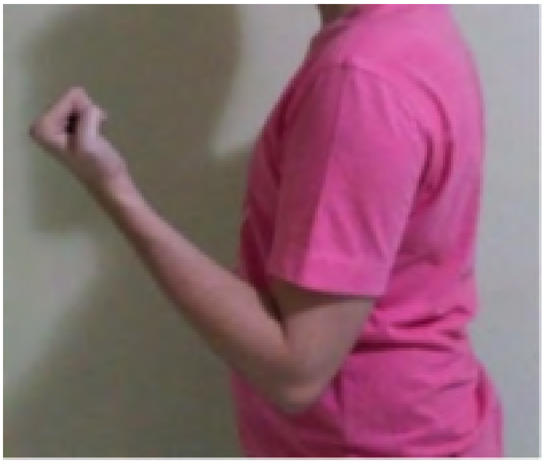


FIGURE 2. **Elbow flexion and extension.**

On defining the vectors, the angle "X" can be calculated (Figure 15) using the Equation 6:

$$X = cos^{-1}\left(\frac{\vec{forearm} + \vec{biceps}}{\vec{forearm} \times \vec{biceps}}\right) \tag{6}$$

To transform the value of radians to degrees, it is necessary to multiply the result by Equation 6. Breaking down equation 6 and adding this transformation we have:

$$X = cos^{-1} \times \left(\frac{(P_x - C_x) * (P_x - C_x) + (P_y - C_y) * (O_y - C_y)}{\sqrt{(P_x - C_x)^2 + (P_y - C_y)^2} + \sqrt{(O_x - C_x)^2 + (O_y - C_y)^2}}\right) \tag{7}$$

2) FLEXION AND EXTENSION OF THE SHOULDER

The shoulder flexion is the movement of raising the arm frontally and keeping the arm stretched throughout the movement. To evaluate this movement, the examination is first selected on the Kinect and then the body of the individual is duly detected by the sensor. Then the subject must rotate 90ô so that the selected shoulder faces the sensor. The ideal position for the subject is when, in the virtual skeleton, the virtual shoulder point is above the reference point in the center of the shoulders, as shown in Figure 4.

The coordinates (x, y) of the shoulder, elbow and middle of the spine must first be defined in order to measure the angle of the shoulder flexion exam. The coordinates of the spine, elbow, and shoulder are defined as (P_x, P_y), (C_x, C_y) and (O_x, O_y), respectively.

When vectoring the members, the arm and the spine, are defined mathematically by:

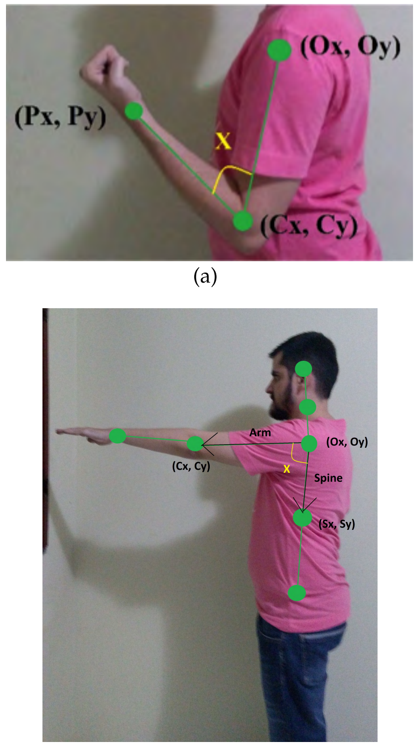
$$arm(x, y) = (C_x - O_x, C_y - O_y) \tag{8}$$

and

$$spine(x, y) = (S_x - O_x, S_y - O_y) \tag{9}$$

To help the understanding here, the vectors and coordinate points in Figure 5 are shown. Once again Equation 1 is applied:

$$X = cos^{-1}\left(\frac{\vec{arm} + \vec{spine}}{\vec{arm} \times \vec{spine}}\right) \tag{10}$$



(a)

(b)

FIGURE 3. **Flexion and extension of elbow.**

FIGURE 4. **Shoulder flexion.**

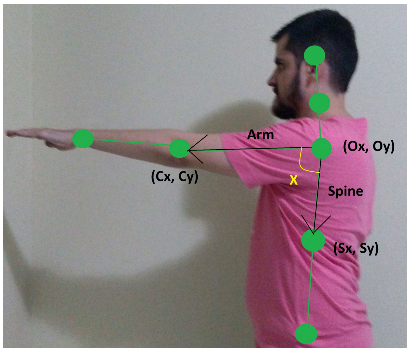


FIGURE 5. Examination of shoulder flexion using the Kinect sensor.

FIGURE 6. Shoulder abduction.

Then expanding it and transforming the radians into degrees:

$$X = cos^{-1} \times \left(\frac{(C_x - O_x) * (S_x - O_x) + (C_y - O_y) * (S_y - O_y)}{\sqrt{(C_x - O_x)^2 + (C_y - O_y)^2} + \sqrt{(S_x - O_x)^2 + (S_y - O_y)^2}} \right) \quad (11)$$

3) ABDUCTION OF THE SHOULDER

The abduction of the shoulder requires the individual to lift the arm laterally always with the arm aligned relative to the trunk, as shown in Figure 6.

The coordinates (x, y) of the four joints (shoulder, the center of the shoulders, the elbow, and the middle of the spine of the subject) must be defined to measure the angle of the shoulder abduction exam. The coordinates of the spine, elbow, shoulder and center of the shoulders are defined as (S_x, S_y), (C_x, C_y), (O_x, O_y) and (M_x, M_y), respectively. In addition to these points, it is necessary to insert an extra point corresponding to the coordinates (I_x, I_y) to create a vector that simulates the slope of the spine from the shoulder, see Figure 7.

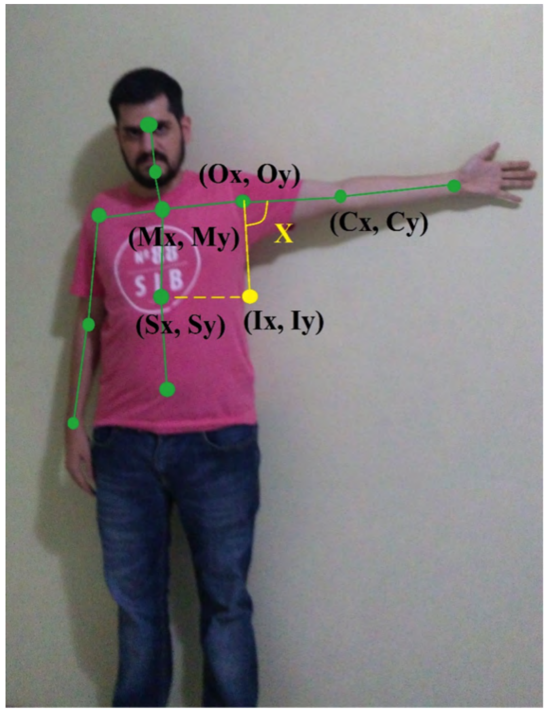


FIGURE 7. Abduction coordinates of the shoulder.

To simulate the point "I", the value of the distance from the shoulder to the center of the shoulders was added to the coordinate of the middle of the spine, as follows:

$$I(x, y) = \left\{ [S_x + (O_x - M_x)] , S_y \right\} \quad (12)$$

With this, the 2 vectors corresponding to the arm and projection of the spine can be obtained, as shown in Figure 7 through the yellow line.

$$arm(x, y) = (C_x - O_x, C_y - O_y) \quad (13)$$

and

$$projection(x, y) = (I_x - O_x, I_y - O_y) \quad (14)$$

Applying equation 1:

$$X = cos^{-1} \left(\frac{\vec{arm} + \vec{projection}}{\vec{arm} \times \vec{projection}} \right) \quad (15)$$

Expanding and converting to degrees, (16), as shown at the bottom of the next page.

Substituting I_x and I_y according to Equation 12, we obtain the final equation for the calculation of the proposed angle, (17), as shown at the bottom of the next page.

4) RADIAL AND ULNAR DEVIATIONS OF THE WRIST

As with the other exams the individual must be at the correct distance and facing the Kinect sensor. Also the calculation of the angle of the deviations is made after defining the coordinates of three points in the body: elbow, wrist and tip of the hand, where the coordinates are represented respectively by (C_x, C_y), (P_x, P_y) and (M_x, M_y) as shown in Figure 20.

To determine the angle corresponding to the radial and ulnar deviations, the coordinate points are initially transformed into vectors, mathematically representing the virtual members as:

$$hand(x, y) = (M_x - P_x, M_y - P_y) \tag{18}$$

and

$$forearm(x, y) = (C_x - P_x, C_y - P_y) \tag{19}$$

Once the vectors have been determined, Equation 1 is applied once more:

$$X = cos^{-1}\left(\frac{\vec{forearm} + \vec{hand}}{\vec{forearm} \times \vec{hand}}\right) \tag{20}$$

Transforming radians into degrees and dividing using the x and y axes, we have, (21), as shown at the bottom of the this page.

5) COMPENSATION

Compensation refers to the level of postural inclination during an examination. Usually this inclination is involuntary, and is frequently related to pain or the instinct to try to complete the desired movement. However, compensation of the individual is always considered during evaluation and treatments. Thus, the veracity of the values obtained during the analysis can be confirmed. In order to determine this compensation in exams, the spine vector, which in this case is delimited by the coordinates of the points referring to the center of the shoulder (C_x, C_y) and spinal base (S_x, S_y) must be defined. The dots and the vector are shown in Figure 9.

For this case, we have the following mathematical formulation:

$$X = cos^{-1}\left(\frac{(S_y - C_y)}{\sqrt{(S_x - C_x)^2 + \left(S_y - C_y\right)^2}}\right) * \left(\frac{180}{\pi}\right) \tag{22}$$

6) DATABASE

All subject information is stored in a database, including their personal data from the registration on the first visit and the angles for each examination and each consultation. All angles and their date of acquisition are stored so that a progression chart of the clinical picture of the individual can be plotted at a later date. The software chosen for the database was Microsoft Access, due to its ease of integration with the Visual Studio compiler. The database is password-locked and theoretically it is only possible to access the data via software or with the file access password.

C. EXERCISE DEVELOPMENT VIA EXERGAMES

In this section, the three exercises that can be performed using the proposed system (GoNet v2) will be analyzed, two of them are based on the Kabat diagonal movement for upper limbs, specifically the shoulders, and one refers to squatting. As in the exams the subject should be at a minimum distance from the Kinect sensor for all proposed treatments so that their whole body appears fully on the computer screen. An area has been drawn virtually in the interface of the program, within which the individual should position their virtual skeleton, as shown in Figure 22, making the system independent of subject size.

To perform the exercise correctly, the subject must be properly positioned according to the instructions given above and then carry out the movements. This exercise consists of initially placing the hand on the opposite side of the waist, forming a diagonal across the subject's body, as shown in Figure 23, it is also essential to keep the arm fully stretched throughout the exercise.

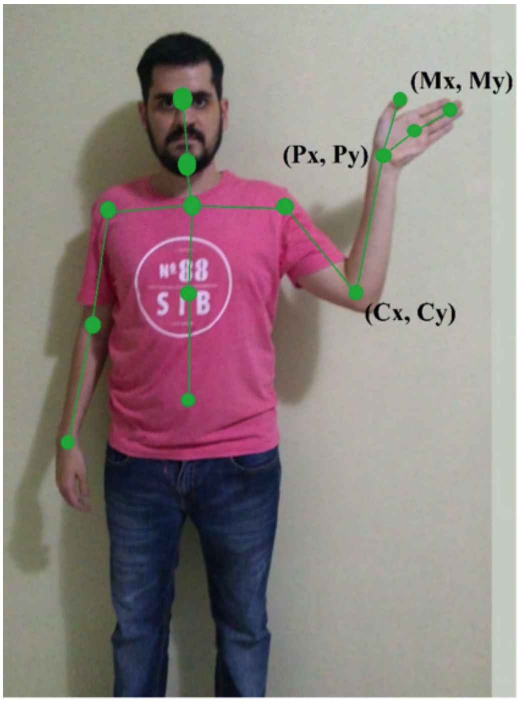
To complete the examination, the subject should perform the diagonal movement with the arm stretched until the hand is in the upper corner and on the opposite side from the starting point, as shown in Figure 12.

Every movement of the hand will be monitored by the system and compared to a previously acquired database for point-to-point comparison of the hand trajectory and to verify the whole execution of the movement. The coordinates (x, y) of 11 points of the trajectory were defined and circular visual feedbacks were established that change color with the passing of the hand so that the subject can follow them during the

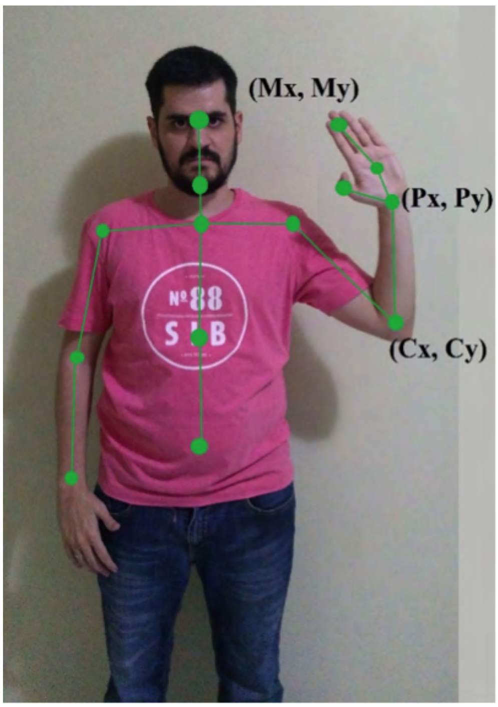
$$X = cos^{-1}\left(\frac{(C_x - O_x) * (I_x - O_x) + (C_y - O_y) * (I_y - O_y)}{\sqrt{(C_x - O_x)^2 + \left(C_y - O_y\right)^2} + \sqrt{(I_x - O_x)^2 + \left(I_y - O_y\right)^2}}\right) * \left(\frac{180}{\pi}\right) \tag{16}$$

$$X = cos^{-1}\left\{\frac{[(C_x - O_x) * \{S_x + (O_x - M_x)\})]}{\sqrt{(C_x - O_x)^2 + (C_y - O_y)^2} * \sqrt{\{[S_x + (O_x - M_x)] - O_x\}^2 + (S_y - O_y)^2)}}\right\} * \left(\frac{180}{\pi}\right) \tag{17}$$

$$X = cos^{-1}\left(\frac{(C_x - P_x) * (M_x - P_x) + (C_y - P_y) * (M_y - P_y)}{\sqrt{(C_x - P_x)^2 + \left(C_y - P_y\right)^2} + \sqrt{(M_x - P_x)^2 + \left(M_y - P_y\right)^2}}\right) * \left(\frac{180}{\pi}\right) \tag{21}$$



(a)



(b)

FIGURE 8. Examination of deviations: a) ulnar and b) radial.

exercise. These points also aim to stimulate the subject to perform the correct movement, and encouraging them to always try to improve.

1) EXERCISE BASED ON SQUATTING

To perform this exercise correctly, the subject must be properly positioned according to the instructions given above

FIGURE 9. Compensation calculation points.

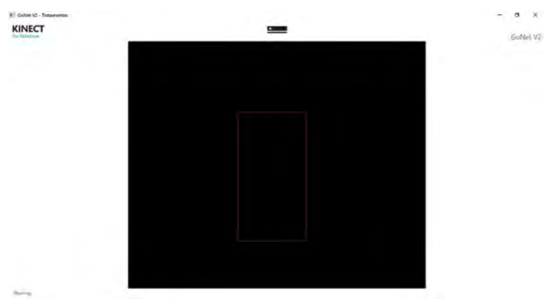


FIGURE 10. subject positioning area.

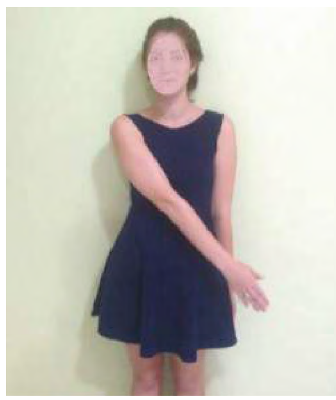


FIGURE 11. Initial position of the exercise based on the Kabat diagonal movement.

and align the hip to a virtual line drawn in the software. The squatting motion consists of initially positioning the feet further apart than the shoulders, always keeping the head up and back straight. Then, slowly, flex the knees and project the hip back, performing the movement similar to that of sitting in a chair, always keeping the posture straight and the head up. The individual lowers him/herself by bending the knees until the knees are at a 90° angle, inhales at the end of the movement and then rises. The full motion is shown sequentially in Figure 13.

FIGURE 12. **Exercise movement based on the Kabat diagonal.**

FIGURE 13. **Squatting movement.**

All movements of the hip and spine are monitored by the system for point-to-point comparison of the hip trajectory, posture angulation, and movement verification. The postural angulation is determined in the same way as the compensation.

Three measurements corresponding to the coordinates of the trajectory were defined, where each point represents a part of the movement. The first point corresponds to a slight descent of the body, the second to a moderate squat, and finally the third to the complete squat position. This sequence of movements encourages the subject to correctly perform the movements, encouraging them to always try to improve. At the end of the movement, the degree of postural inclination is evaluated as well as the point reached in the squat.

D. STATISTICAL ANALYSIS

The data obtained corresponding to the range of motion of each user were analyzed using the statistical program Statistical Package for Social Sciences (SPSS), version 13.0. In order to analyze the GoNet reproducibility, the Intraclass Correlation Coefficient (ICC) and Cronbach's Alpha were used, and then the angles obtained were compared with their mean and standard deviations, evaluating the accuracy of the instrument in relation to traditional goniometry.

To compare the proposed system against the conventional model, the differences between the maximum average and the worst case average are used, for each exam performed. This difference is obtained by subtracting the lowest mean minus its deviation from the highest mean plus its deviation. For example, 2 means A and B and their derivations a and b, where A is greater than B, then the value of the maximum difference is calculated by:

$$Dmax = [(A + a) - (B - b)] \tag{23}$$

Dmax is used in the comparison with the maximum range of motion for each evaluation in order to verify its relevance during the examination. For example, normally the range during the shoulder abduction exam varies between 0 and 180°, so the difference in this case is given as:

$$relevance = \frac{Dmax}{180} \times 100 \tag{24}$$

In addition to the statistical evaluation of the equipment with the above tests, an evaluation was carried out by health professionals. Occupational Therapists and Physiotherapists of the Nucleus of Integrated Medical Attention (NAMI) of the University of Fortaleza were asked to evaluate the tool and suggest any improvements. A questionnaire composed of 12 questions was applied; 9 questions were objective and 3 subjective.

The questionnaire was given to 12 professionals, and then the data were computed and analyzed in the SPSS, calculating Cronbach's alpha coefficient, according to the equation:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum_{i=1}^{k} S_i^2}{S_{total}^2}\right) \tag{25}$$

in which k varies from 1 to 9 and represents the questions of the questionnaire, the number of health professionals who participated in the questionnaire, in this case 12, Si2 the variance n of the people's scores to the i_{th} item ($i = 1, 2, \ldots, k$), ${S_{soma}}^2$ and the variance of the totals $T_j (j = 1, 2, \ldots, k)$ of scores for each specialist.

The variances are calculated by the equation:

$$S^2 = \frac{\sum (x - \bar{x})^2}{n}, \tag{26}$$

where x is the value of the answer of the question and $\bar{x}$ the mean of the values.

III. RESULTS

This hybrid system developed in this work involves four main parts: (i) health professional, (ii) personal computer, (iii) Kinect sensor and (iv) patients as shown in Figure 14. The professional is responsible for managing the system, as well as registering the patients and storing their information on the database. In addition, the professional must interact with the patient to explain the correct movements and help if necessary. The computer performs all the data processing, data storage and is the interface with the professional. The Kinect is the sensor that captures all the movements made by the patients, and transmits them to the computer for later analysis. Finally, there is the patient, who presents some type of motor limitation and needs to be evaluated to determine his/her clinical situation, leading to possible treatment. In this study, the proposed approach is based on Kinect version one.

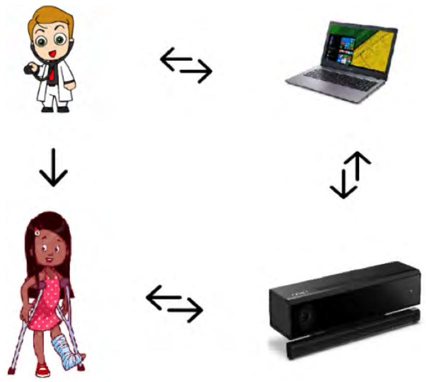


FIGURE 14. Steps for using GoNet.

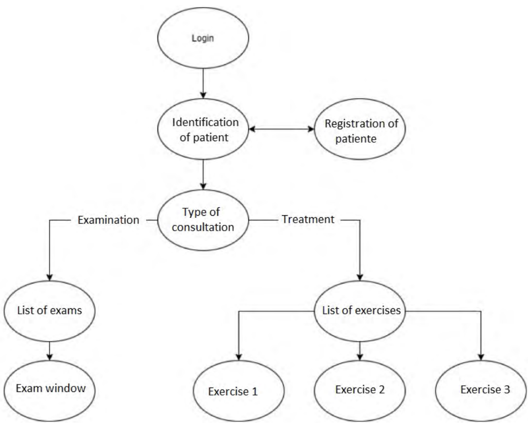


FIGURE 15. Interface flowchart.

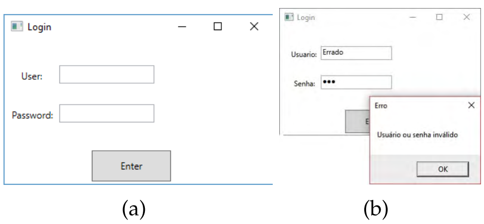


FIGURE 16. Interface: a) Login and b) Login error.

A. SYSTEM INTERFACES

Figure 15 presents the flowchart with the ten interfaces of the proposed system, all of which are described below.

To start, the system loads the Login interface (Figure 16(a)), whose function is to identify the professional who will be operating the equipment, ensuring that only registered and previously trained professionals can use the GoNet v2, thus preventing inappropriate access as shown in Figure 16(b).

After the identification of the professional, patient identification is required. The patient can be found in the database using his/her full name or National ID number; however, if there is a new patient he/she can be registered by clicking on the corresponding button, see Figure 17.

Figure 18 needs to be filled out to register a new patient and the data will be stored in a database for future consultation if needed.

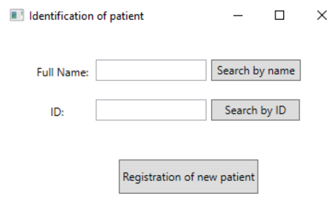


FIGURE 17. Patient identification.

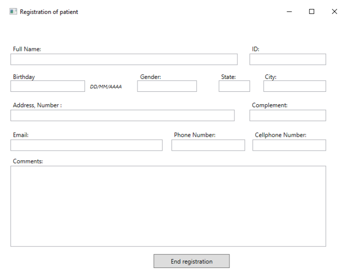


FIGURE 18. Register of a new patient.

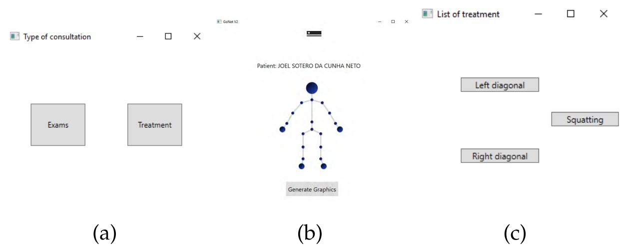


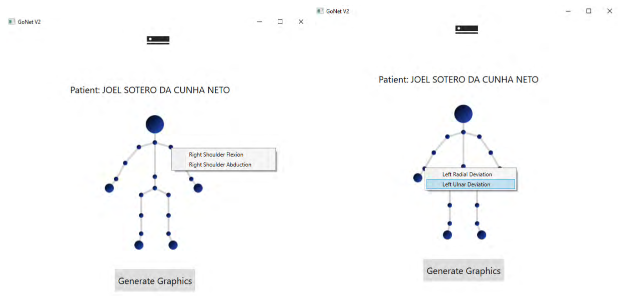
FIGURE 19. Interfaces for a) procedure selection, b) examinations, and c) treatments.

After correct identification of the patient, an interface related to the type of consultation, exams or rehabilitation is shown (see Figure 19(a)) in which the professional will define which procedure is to be adopted. If examine is selected the GoNet will open the interface related to exams (Figure 19(b)), or if treatment is selected the interface will open for the treatments, Figure 19(c)).

The exam selection interface can be loaded in one of two ways, the first by placing the mouse cursor over the joint to be evaluated and then click on the exam (Figure 20). The second way uses a voice command, pronouncing the name of the exam in English, for example, Left shoulder abduction, for abduction of the left shoulder.

All the exams are applied individually via the same interface (Figure 21), and loaded after the exam selection (Figure 19(b)) and region to be evaluated (Figure 20). The only modification is the range of motion, which is determined by professional, according to the calculations explained in the previous chapter.

In the interface corresponding to the choice of treatments (Figure 19(c)), the professional can choose two types of exercises, the first one based on the Kabat diagonal movement, separated by left and right limbs and the second based on squatting. If the Kabat diagonal movement



(a) (b)

FIGURE 20. Exam choice.

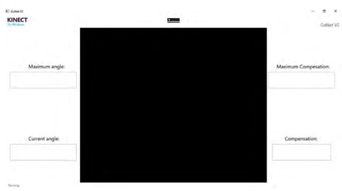
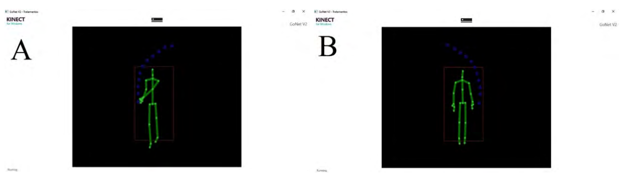


FIGURE 21. Exam interface.



(a) (b)

FIGURE 22. Exergame based on the Kabat diagonal movement. (a) for the right arm and (b) for the left arm.

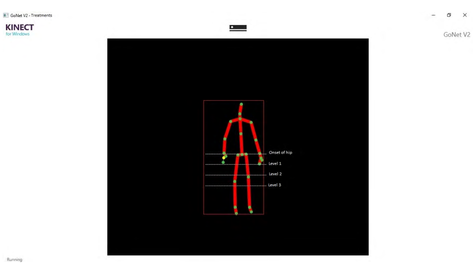


FIGURE 23. Exergame based on squatting.

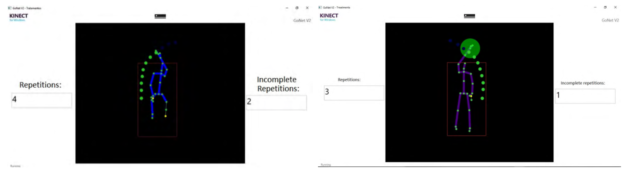
exercise is defined, an exergame based interface will be loaded (Figure 22).

If the option is for the squatting exercise, a window with the exergame of the proposed movement, is loaded (Figure 23).

B. EXERGAME TESTS

In order to validate the exergames, functional tests were carried out with more than one participant. The participants were previously informed concerning the procedures to be followed and how each exercise should be done.

During the tests, the following items were evaluated: patient movement, software functionality and automatic counting of movements. The patient movement was evaluated



(a) (b)

FIGURE 24. Kabat diagonal movement test.

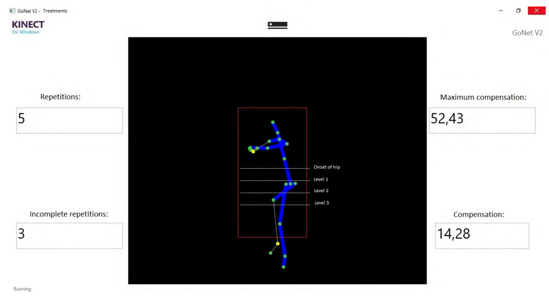


FIGURE 25. Exergame of the squatting.

as to whether it was performed according to the Kabat diagonal movement. The functionality of the software was assessed according to the movement of the patient, and if the software detected the movement and by the color changes of the blue ellipses on the interface. Two text boxes were added to count the incomplete repetitions (unable to complete the diagonal movement) and the complete repetitions, as illustrated in Figure 24.

A similar method was used for the squatting exam, but in addition to counting the complete and incomplete exercises, the patient compensation was calculated to verify their posture during the exercise, as shown in Figure 25.

C. TESTS AND VALIDATION OF EXAMS THROUGH GoNet v2

Throughout the development, the system was evaluated systematically in order to detect possible failures or improvements that could be considered. Initially, the tests were performed disregarding the goniometer, and were only verified by the naked eye, if the movements were being executed and mapped correctly. These tests and validation were carried out in the following order: shoulder abduction (Figure 26), shoulder flexion (Figure 27), elbow flexion and extension (Figure 28), radial deviation (Figure 29), and ulnar deviation (Figure 30).

The intra-examiner and inter-examiner reproducibility were analyzed, and the intraclass correlation coefficient (ICC) values are shown for shoulder flexion/extension, shoulder abduction/adduction and ulnar deviation ranges in Table 1, where the higher the value is, the more precise the tool is. In the radial deviation, a significant difference occurs when the inter-examiner ICC is evaluated, showing a low precision which is due to the uncertainty of its measurement as it did not present good results in the angle measurements.

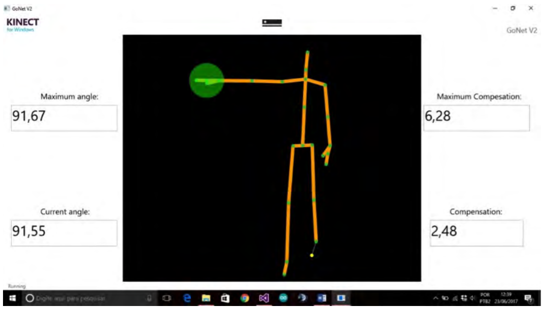


FIGURE 26. Shoulder abduction using GoNet.

FIGURE 27. Shoulder flexion using GoNet.

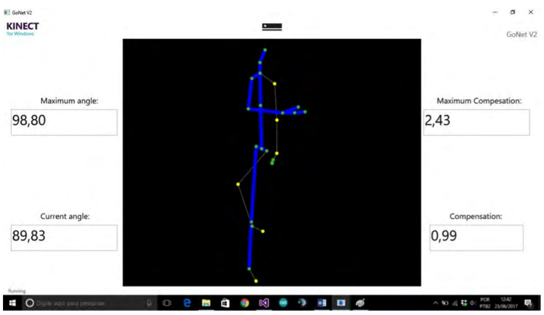


FIGURE 28. Elbow flexion / extension using GoNet.

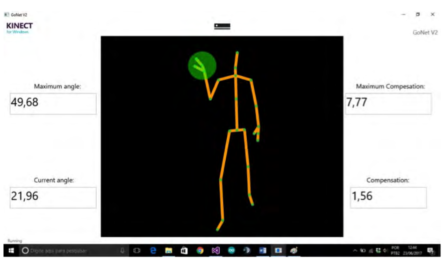


FIGURE 29. Radial deviation using GoNet.

The statistical results for the ICC values for shoulder abduction and flexion/extension of the shoulder and elbow are very satisfactory as all the values were above 0.9, both for intra-examiner and for inter-examiner, proving that the system is reliable. Cronbach's alpha, which is another way of calculating reliability, shows that the statistical values obtained are very satisfactory when referring to abduction of shoulder

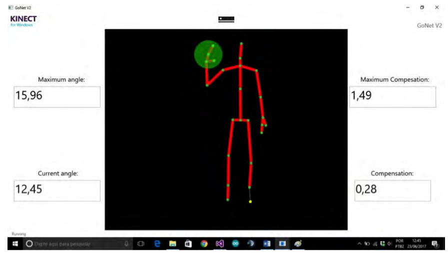


FIGURE 30. Ulnar deviation using GoNet.

TABLE 1. Intra-examiner (IA) and inter-examiner (IE) reproducibility by ICC.

Articular Range (Degrees)	IA	IE	Cronbach Alpha
Shoulder Flexion/Extension	0.97	0.91	0.98
Shoulder Abduction/Adduction	0.98	0.97	0.96
Elbow Flexion/Extension	0.97	0.90	0.98
Radial Deviation	0.64	0.21	0.78
Ulnar Deviation	0.77	0.89	0.87

TABLE 2. Comparison of angles obtained by goniometry and GoNet.

Articular Range (degrees)	Goniometry	GoNet	p
Shoulder Flexion/Extension	86.9 ± 2.2	89.7 ± 1.5	0.04*
Shoulder Abduction/Adduction	89.3 ± 1.7	90 ± 1.4	0.4
Elbow Flexion/Extension	90 ± 3.2	89.9 ± 1.5	0.9
Radial Deviation	18.3 ± 6.5	11.7 ± 3	0.01*
Ulnar Deviation	40.1 ± 14.9	27.9 ± 12.5	0.01*

TABLE 3. Comparative details of accuracy and relevance, using Articular Range (AR), Maximum Difference (MD) and Relevance (R).

AR [°]	MD [°]	Parameter[°]	R [%]
Shoulder Flexion/Extension	6.5	0-180°	3.61
Shoulder Abduction/Adduction	3.8	0-180°	2.11
Elbow Flexion/Extension	4.6	0-145°	3.17
Radial Deviation	16.1	0-45°	35.77
Ulnar Deviation	39.6	0-20°	198

and flexion/extension of shoulder and elbow. According to current literature, the acceptable value in regard to the reliability of the instrument can vary from 0.7 to 0.85; and once again the closer to 1, the more reliable the instrument is, and thus the results obtained by GoNet v2 demonstrate that the system is very reliable.

Table 2 shows the comparative results between the GoNet and the goniometer, using the mean and standard deviation results of ten healthy subjects, each of whom performed a single movement each time. As previously mentioned, the individual was asked to maintain an angulation of approximately, and was assisted by a fixed apparatus to guarantee this angulation. Then, the range of motion evaluation was carried out with the GoNet v2 and the goniometer.

The values of the angles for the examinations of abduction of shoulder, and flexion/extension of shoulder and elbow are very similar. The radial and ulnar deviations for both measurement systems gave unsatisfactory results, which was mainly due to the limitation of the distance between the

TABLE 4. Questionnaire responses.

Objective questionnaire questions	Extremely probable	Very likely	Unlikely	Not at all probable
1 - Can the proposed system help in measuring the range of motion of the patient's upper limbs?	33.33%	66.67%	-	-
2 - Can the proposed system help in the evolution of patient rehabilitation?	25%	75%	-	-
3 - Can the proposed system clearly assist in the "motivation" factor for the patient during the examination / treatment?	58.33%	41.67%	-	-
4 - Can the proposed system increase the accuracy of the ROM evaluation?	33.33%	66.67%	-	-
5 - Can the proposed system speed up the patient examination / rehabilitation process?	50%	41.67%	8.33%	-
6 - Are the activities presented in the proposed examination aligned with the objectives of the traditional exam?	33.33%	66.67	-	-
7 - Are the activities presented in the proposed treatment aligned with the objectives of the traditional exam?	25%	75%	-	-
8 - Can the proposed system jeopardize (negatively influence) patient evaluation or rehabilitation?	-	8.33%	75%	16.67%
9 – Would the patient reject the use of the system in any way?	-	8.33%	75%	16.67%

patient and the instrument that made it difficult to trace small points, such as the wrist and fingertips, precisely. However, taking into consideration the standard deviations, the mean angulation obtained is satisfactory for both approaches, confirming the effectiveness of the proposed system. Any value of 'p' greater than 0.05 indicates that there is no statistically significant difference. For the deviations the difference is unreliable, and the low 'p' score for the flexion/extension of the shoulder was due to the low number of patients used in the analysis, which impaired the statistical calculation.

The maximum difference between the averages of the GoNet angles and the goniometer is calculated using Equation 2 and 3 the methodology and using the data presented in Table 2. For each exam, the parameter (maximum range) and relevance (ratio of error to parameter) of this difference are presented in Table 3.

The shoulder flexion/extension and abduction/adduction, and elbow flexion/extensions exams obtained low scores but also showed a significant similarity between the two measuring instruments used, as indicated by the values corresponding to the angulation differences in the order of 6.5, 3.8 and 4.6 degrees, respectively. The difference between the instruments cannot be considered as an error, since they have different measuring methods and criteria. Since the goniometer is considered the gold standard, then the GoNet (v2) must be considered 100% reliable due to the numerous justifications described above.

On the other hand, the ulnar and radial deviation data produced unsatisfactory values for both measuring systems. The radial deviation had a maximum difference of 16.1°, representing approximately 36% of relevance during the measurement. In the literature, an exact value of relevance is not established to validate a given exam, however, in this work, a value of up to 5% was considered sufficient to indicate that the tool has good results. An even greater difference for ulnar deviation, which presents a relevance of approximately 200%, suggests that the system is not appropriate for this type of examination.

D. PROFESSIONAL ASSESSMENT QUESTIONNAIRES

This hybrid tool developed here was also validated by professionals from the Occupational Therapy Center, who were invited to participate in the presentation of the new instrument based on Kinect and had the opportunity to use it to test its possibilities and to analyze its viability as an alternative examination and/or treatment or as a complement. Twelve specialists from the NAMI Occupational Therapy Center were present at the demonstration, which was carried out by the author of the work and was open to tests after the explanation. After the presentation and demonstration of the tool, the specialists present were given a questionnaire to complete.

The questionnaire was composed of 12 questions, 9 objective questions with 4 options each: Extremely probable, Very likely, Unlikely and Not at all probable, and 3 subjective questions aiming to obtain suggestions about the positive and negative factors in regard to the use of the instrument.

Table 4 shows the percentages of answers for each of the 9 objective questions. All the questions that were expected to have favorable answers in regard to the system (questions 1 to 7) achieved this. The questions considering the possibility of the patient rejecting the system (questions 8 and 9) resulted in the vast majority of professionals agreeing that there was no danger or possible harmful situations for patients.

IV. CONCLUSIONS

A tool was developed with the Kinect v2 sensor to evaluate range of motion dynamically and non-invasively and to measure angles with precision in order to provide complementary assistance in rehabilitation treatments. A database was also created for the storage of the patient information, which could generate reports and graphs showing the progress of patients.

A statistical evaluation was also performed using the Intraclass Correlation Coefficient (ICC), which verified the accuracy of the instrument for all the examinations, except for the radial deviation, as well as an evaluation of the accuracy of the instrument by comparing the maximum error with the range of each movement.

Thus, in conclusion we can say that the use of a questionnaire among professionals in this area showed that the instrument achieved a good acceptance and through the validations met all the criteria of precision and accuracy for the abduction of shoulder and flexion/extension of shoulder and elbow exams; however, the tool was not appropriate for the evaluation of the ulnar and radial deviation exams. A functional exercise platform based on real exercises used on a daily basis was also developed and tested, enabling and aiding rehabilitation.

Since this project was already based on 'future projects' from a previous work (GoNet), little is left to be said on what can be done to improve the system. But as a future work based on this present work we can suggest: The development of a more attractive and friendly interface; Implementation of a monitoring system through the Kinect RGB camera, so that the evaluation and treatment can be done remotely by the professional; and finally try to make GoNet v2 the new gold standard for measuring ROM

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JOEL S. DA CUNHA NETO received the B.Sc. degree in control and automation engineering from the University of Fortaleza, Fortaleza, Brazil, and the M.Sc. degree from the Graduate Program in Applied Informatics, University of Fortaleza, in 2017. He has experience in computer systems, mainly in the research fields of autonomous systems, artificial intelligence, biological signal processing, image processing, residential automation, vehicle automation, biomedical engineering, microcontrollers, and industrial automation and programming.

PEDRO P. REBOUÇAS FILHO received the Ph.D. degree in teleinformatics engineering from the Federal University of Ceará, Fortaleza, Brazil, in 2013. He is currently a Professor with the Instituto Federal de Educação, Ciencia e Tecnologia do Ceará, Limoeiro do Norte, Brazil. His current research interests include computational vision, mainly using medical images.

GUILHERME P. FERREIRA DA SILVA received the degree in physiotherapy from the University of Fortaleza in 2009 and the Ph.D. degree in medical sciences from the Federal University of Ceará in 2017. He is currently a Professor in physiotherapy with the Universidade de Fortaleza and the Scientific Director of the Associação Brasileira de Fisioterapia Respiratória, Cardiovascular e Terapia Intensiva. He has experience in the areas of cardiopulmonary rehabilitation, respiratory and cardiovascular physiotherapy, hospital physiotherapy, clinical research, quality of life, respiratory, and cardiovascular diseases.

NATÁLIA B. DA CUNHA OLEGARIO received the B.Sc. degree in physiotherapy and the M.Sc. degree in collective health from the Universidade de Fortaleza, Fortaleza, Brazil, in 2012 and 2014, respectively. She has experience in physiotherapy and occupational therapy, and she has been involved in the same fields.

JOÃO BATISTA F. DUARTE received the B.Sc. degree in physics from the Universidade Federal de Santa Maria, Santa Maria, Brazil, in 1993, and the M.Sc. and Ph.D. degrees in physics from the Federal University of Ceará, Brazil, in 1995 and 1998, respectively. He has been a Professor with the Graduate Program in Applied Informatics, Universidade de Fortaleza, since 2001. His research interests include heat transference, thermodynamic, and thermal processes, acting on the following subjects: combustion, porous media, gaseous fuels, and combustion and biomass.

VICTOR HUGO C. DE ALBUQUERQUE received the degree in mechatronics technology from the Federal Center of Technological Education of Ceará, in 2006, the M.Sc. degree in teleinformatics engineering from the Federal University of Ceará, in 2007, and the Ph.D. degree in mechanical engineering, with emphasis on materials, from the Federal University of Paraíba in 2010. He is currently an Assistant VI Professor with the Graduate Program in Applied Informatics, Universidade de Fortaleza. He has experience in computer systems, mainly in the research fields of applied computing, intelligent systems, visualization and interaction, with specific interest in pattern recognition, artificial intelligence, image processing and analysis, automation with respect to biological signal/image processing, image segmentation, and biomedical circuits and human/brain–machine interaction, including augmented and virtual reality simulation modeling for animals and humans. He has carried out research in the microstructural characterization field through the combination of non-destructive techniques with signal/image processing and analysis, and pattern recognition.