Comparison of Shoulder Range of Motion Evaluation by Traditional and Semi-Automatic Methods

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Abstract—**This article compares the results obtained from applying two methods of measuring the range of motion in the upper extremity. From a descriptive, cross-sectional study, measurements were made using the most widely used and traditional method in the health area known as goniometry as well as a semi-automatic method developed using new technological tools. The results demonstrated that the technique has a high sensitivity and can analyze static body positions and movement evolutions, expanding its applicability range.**

Keywords—**range of motion, technological tools, goniometry, artificial vision, physical therapy**

I. Introduction

The range of motion in the shoulder joint is a commonly used clinical criterion for diagnostic purposes and to monitor treatment effectiveness. In this joint, flexion-extension movements are performed in the sagittal plane around a transverse axis: extension is a low amplitude movement from 45º to 50º, while flexion is a high amplitude movement of 180º, as well as abduction, also of 180º, which is a movement that moves the upper extremity away from the trunk in a frontal plane around a sagittal axis [1].

Consequently, measuring joint range of motion is considered an essential activity in physical therapy evaluation, which is traditionally performed using the traditional or digital goniometer. This is a low-cost and easily stored device. However, its use is tedious, and the accuracy of the measurements depends on the experience of the examiner, who requires a lot of time to perform the exploration [2]; both hands are needed to fix the segments, and a clear visual estimate is needed for alignment and reading the measurement, which could result in inconsistent results [3, 4].

Technological advances offer the possibility of using non-invasive and easy-to-use equipment [5]. However, to optimize their use, it is necessary to know the reliability of these methods [6, 7]. The purpose of this study was to create a semi-automatic algorithm based on the use of a structured light sensor that allows for three-dimensional reconstruction of some user positions. The results obtained by this method were compared with those obtained by a traditional method in the evaluation of some upper limb motion arcs, through a descriptive, cross-sectional study that was applied to a group of healthy young adults. Their motion arcs were measured with both proposed methods, which were recorded and systematized. Subsequently, a statistical analysis of the information was carried out, indicating that the semi-automatic method is as useful as the traditional one, with many advantages.

Technologically, there are tools that researchers often use to study human body movements [8–21]. A highly relevant tool is motion capture laboratories (MoCap System), which use photogrammetry techniques to estimate the three-dimensional position of the body [22–25]. These laboratories can use different types of sensors to perform recognition. One option is using infrared cameras that track self-reflecting markers (passive sensors). Another option is using suits with active markers that usually emit light through LEDs. Additionally, some laboratories use Inertial Units (IMU) [26, 27], which allow for the recording of translational and rotational movements (6 DOF). Other low-cost techniques that do not require markers rely on image and video analysis using computer vision [28, 29]. They can use normal cameras such as Kinovea [30–32] or Dartfish software [33], or they can use depth cameras that emit structured light patterns such as the Intel RealSense [34, 35] and Microsoft Kinect sensors [36–39]. This article will employ the latter type of sensors for the three-dimensional reconstruction of the human body.

II. Materials and Methodology

The sample selected by convenience corresponded to a group of university students who were consulted by means of informed consent for their voluntary participation in the study, which was carried out in accordance with the ethical guidelines of Helsinki [40]. Declaration of ethical principles and the Colombian legal

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norms that regulate research in humans [41]. Oral and written information was provided to the subjects, and they were informed of their right to withdraw at any time without explanation. As inclusion criteria, subjects were considered to be over 18 years old, healthy, and have no injuries or alterations in their motion arcs in their upper limbs.

The traditional evaluation method called goniometry was performed using 24 cm a transparent plastic goniometer with two movable arms. To measure the range of motion, the center of the goniometer was fixed on the joint axis of motion [33]. The goniometer's fixed arm was placed towards the standardized reference points on the humerus, and the movable arm was positioned towards the reference points of the upper limb of the person, for the right shoulder's flexion, extension, and abduction movements.

The measurement values were given in degrees with one-degree intervals. The measurement was taken from a neutral position of the shoulder joint, taking into account the following criteria:

- Examinee's position
- Stabilization of the proximal segment
- Palpation and identification of the bony landmarks
- Alignment of the goniometer with the bony landmarks
- Measurement of the joint range of motion
- Reading the measurement result

To record the measurements, each study subject was examined by both evaluators to determine inter-evaluator reliability. Each evaluator repeated each measurement three times on the same day, and eight days later, the evaluation procedure was repeated (test-retest reliability).

The semi-automatic evaluation system was based on the development of algorithms that are essentially composed of two parts: the first corresponds to the recognition of the significant points of the body in a three-dimensional space to reconstruct the kinegram. The second is the vectorial interpretation of the points to perform the calculations corresponding to the range of motion.

The Kinect device was used for recognizing the significant points of the body. This device is based on a structured light system that emits light patterns, which expand as the distance from the impact area (in this case, the human body members) increases. The size of these patterns is measured using an infrared sensor or camera. Additionally, the Kinect system has an RGB camera that captures images or frames of the working environment.

The Software Development Kit (SDK), provided by the manufacturer of the Kinect device includes functions that estimate 20 points to represent the user's body position. Fig. 1 illustrates the overlap of the estimated points on the RGB image, and it is possible to observe the lines between the points that represent the user's two-dimensional kinegram.

Subsequently, an algorithm was generated that transforms the estimated points of the user's kinegram to be represented from the environment's coordinate system. The three-dimensional representation is very useful as the user can be observed from multiple views to observe a particular detail. Fig. 2 illustrates an example of the representation of the same kinegram from another viewpoint.

Figure 1. RGB image and complete kinegram overlaid on the two-dimensional image.

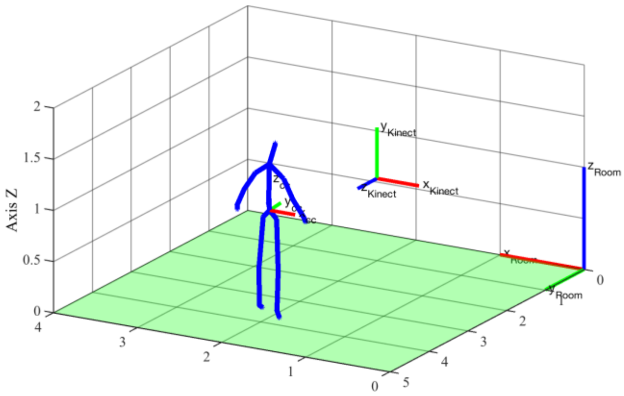

Figure 2. Three-dimensional representation of the user's kinegram.

Once the three-dimensional representation of the kinegram is obtained, the calculation of the movement arcs in the right shoulder is carried out. In the case of flexion/extension movement, an orthonormal reference system is generated in the right shoulder, as illustrated in Fig. 3. From this coordinate system, a change of base or transformation is carried out to calculate the three-dimensional coordinates of the right elbow with respect to this system [42]. This change of coordinates is carried out using the inverse of the homogeneous transformation matrix of the right shoulder with respect to the Kinect sensor, as illustrated in Eq. (1).

$$ {}^{RS}P_{RE} = {}^{K}A_{RS}^{-1}\ {}^{K}P_{RE} \tag{1} $$

where:

${}^{K}P_{RE}$: Right elbow coordinates with respect to the coordinate system of the Kinect sensor.

${}^{K}A_{RS}$: Homogeneous transformation matrix of the right shoulder with respect to the Kinect sensor.

${}^{RS}P_{RE}$: Right elbow coordinates with respect to the coordinate system of the right shoulder.

The angle corresponding to the flexion or extension can be calculated from the Y and Z coordinates of the position of the right elbow with respect to the shoulder, as described in (2).

$$\propto_{FE} = atan2\left({}^{RS}Py_{RE}, -{}^{RS}Pz_{RE}\right) \quad (2)$$

where:

$\propto_{FE}$: Flexion/Extension Angle

${}^{RS}Py_{RE}$: Coordinate on the Y axis of the right elbow relative to the right shoulder coordinate system.

${}^{RS}Pz_{RE}$: Coordinate on the Z axis of the right elbow relative to the right shoulder's coordinate system.

In Fig. 3, the user's kinegram can be seen, illustrating the coordinate systems as well as the sagittal and frontal planes translated in a parallel manner to the location of the right shoulder. This figure shows of flexion/extension movement arc, where the illustrated position corresponds to 102.68º.

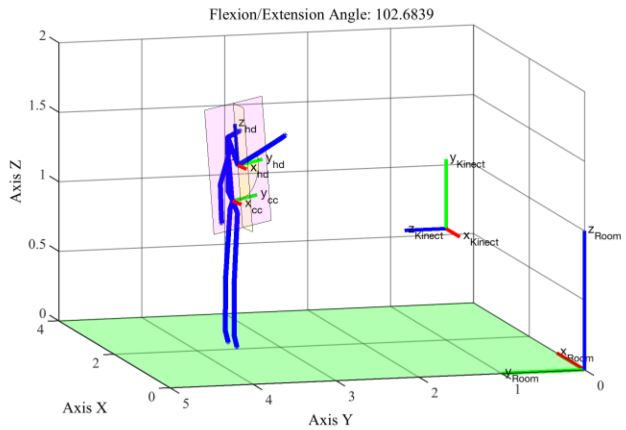

Figure 3. Arc of movement corresponding to flexion.

To calculate the angle of abduction or adduction, the X and Z coordinates of the position of the right elbow with respect to the coordinate system of the right shoulder are used, as shown in (3).

$$\beta_{AbdAdd} = atan2\left({}^{RS}Px_{RE}, -{}^{RS}Pz_{RE}\right) \quad (3)$$

where:

β_{AbdAdd}: Angle of Abduction/Adduction

${}^{RS}Px_{RE}$: Coordinate along the X-axis of the right elbow with respect to the coordinate system of the right shoulder.

${}^{RS}Pz_{RE}$: Coordinate on the Z-axis of the right elbow with respect to the right shoulder coordinate system.

In Fig. 4, the movement of abduction/adduction can be seen, which is represented by a cyan-colored circular arc. In this case, the angle obtained was 105.65º.

It should be noted that the developed algorithms have the capability to process 29 images per second. This feature allows for its use in both rest and movement segment studies. Once the corresponding algorithms for the semi-automatic method have been developed, two types of experiments are performed. The first aims to compare the two measurement methods against the measurement of the maximum angles developed within the motion arc. The second experiment aims to establish standardized conditions for the precision and repeatability measurements of the proposed method. The details of the two types of experiments are presented below.

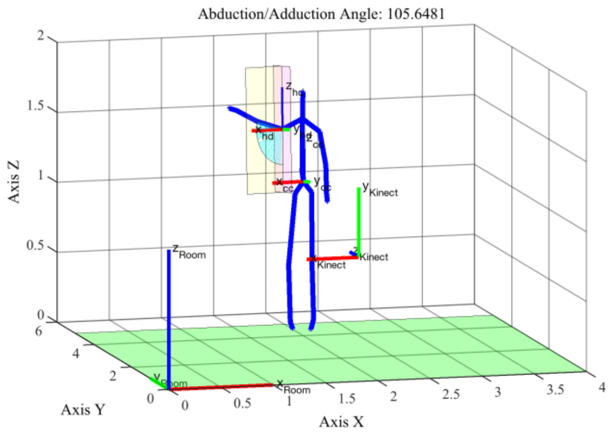

Figure 4. Arc of motion corresponding to abduction/adduction.

A. Comparison Experiments between Measurements Obtained by Various Evaluators

To compare the measurement of joint movement arcs using the traditional and semi-automatic methods, an experimental design was carried out in a sample of 14 young users or patients. Two expert physiotherapists measured the joint movement arcs of flexion, extension, and abduction of the right shoulder for each patient using the traditional method (using a goniometer), recording the obtained data in a record for each subject. Then, measurements of the three joint movement arcs (maximum value) were taken using the previously described semi-automatic method. A second set of measures was taken using both methods eight days after the first test.

The measurements were recorded on video to verify the correct execution of the joint movements, discarding invalid measures, which is why the sample of subjects was reduced to 10.

The results and their corresponding analysis are presented in Section III.

B. Experiments Performed by Measuring Fixed Movement Arcs to Make Conditions More Homogeneous

Since the same subject can lift the upper limbs to a greater or lesser extent in different tests (since they are performed at different moments in time), it was considered to carry out an experiment in which marks are fixed, and the subjects are asked to lift the right arm to one of them, to take the measurement using the semi-automatic algorithm and the traditional method, trying to unify the conditions, mainly posture and the amplitude of the movement, as show in Fig. 5.

The established movements according to the marks allow for better uniformity of measurements across different methods and more precise verification of the data through statistical analysis. This is because the arm's position does not change significantly while the measures are being taken, as shown in Fig. 6.

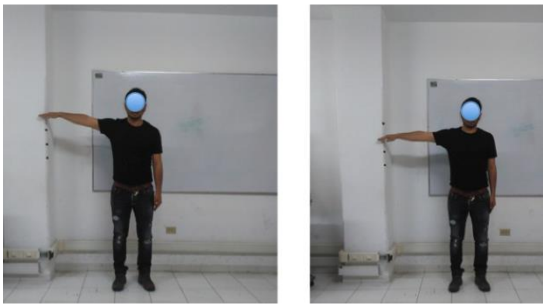

Figure 5. Subject raising the right arm to a predetermined mark to control the movement amplitude.

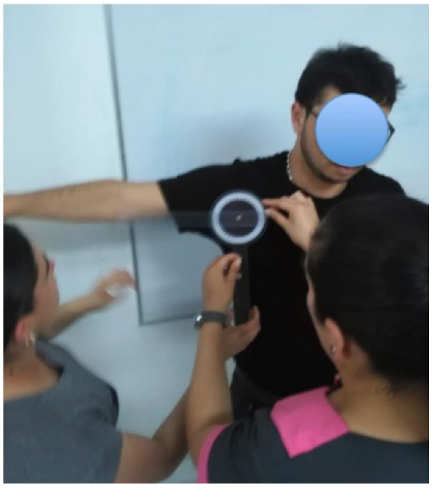

Figure 6. Measurement of the range of motion using a goniometer.

In this experiment, a sample of five healthy subjects is selected perform four movements according to the pre-established marks. The physiotherapists take the measurements with the reference instrument (goniometer), and later a significant number of measurements are taken using the semi-automatic method. Since the subjects perform the movement arc starting from a reference position (zero degrees abduction), a sample of 100 items of data is taken when the upper limb reaches the mark.

To process the data in an appropriate way, a statistical description of the data was carried out. It should be noted that from each test (subject lifting the arm to a mark), 100 measurements were obtained using the semi-automatic method, generating 400 items of data per subject for a total of 2000 measurements throughout the experiment.

Fig. 7 shows the data obtained for a subject when performing the movement from the rest position to the upper mark. This figure shows the evolution of the movement.

As this objective of this study is to take measurements in a stationary state, the algorithm automatically takes a sample of 100 pieces of data as the subject reaches the target mark. The red color in Fig. 7 represents this data. Additionally, this data is illustrated in a scale that improves their visualization (Fig. 8). It should be noted that the developed algorithm could even be extended for more comprehensive and advanced studies that involve variables such as speed.

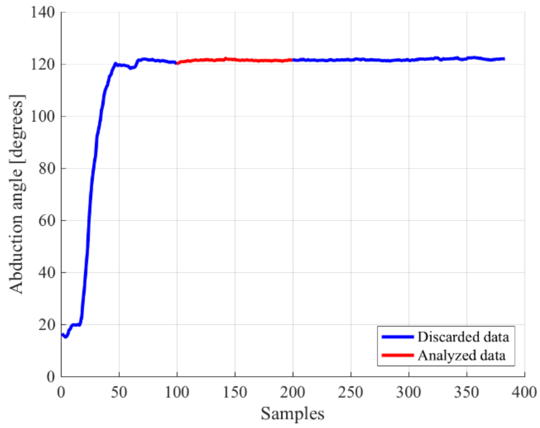

Figure 7. Evolution of the movement arc of a subject indicating the upper mark, measured by the semi-automatic method.

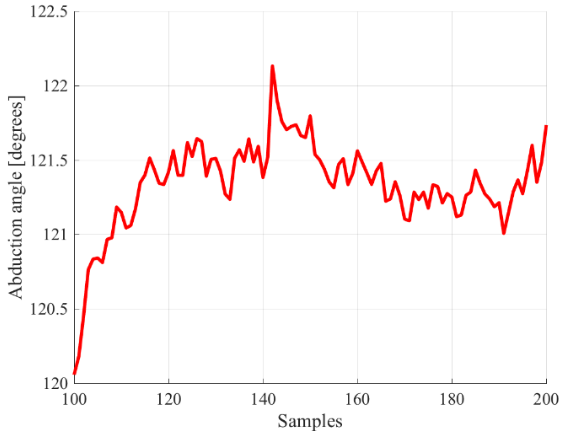

Figure 8. Measurements taken by the semi-automatic method for a subject indicating the upper mark.

Additionally, Fig. 9 shows a histogram representing the frequency of the data obtained according to its value. This allows for quickly obtaining the mode and the level of dispersion of the obtained data. The results obtained and their corresponding analysis for the entire sample are presented in the next section.

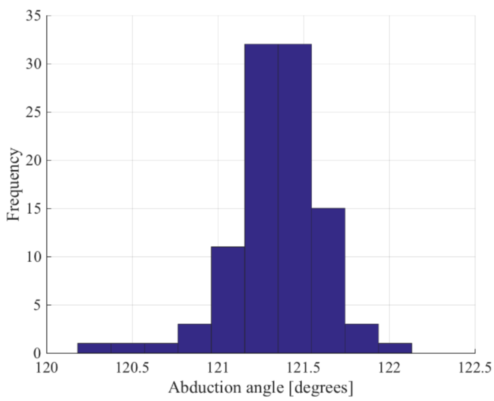

Figure 9. Example of a histogram of the analyzed data for a subject, indicating the upper mark.

III. Results

Following is the presentation of results for the two types of experiments conducted.

A. Comparative Experiments between Measurements Obtained by Various Evaluators

In Fig. 10, a bar graph presents comparison between the errors of the maximum flexion arc measurements in the two experimental sessions carried out by the three evaluators. It is highlighted that Evaluators A and B used the traditional method, while Evaluator C used the semi-automatic measurement system. A significant variation in inter-evaluator measurements can be observed. These variations are common considering that the movement developed by the subjects can vary, depending on whether they had previously performed similar movements.

Additionally, in the case of semi-automatic measurement, it must be taken into account that the system evaluates the evolution of the movement, obtaining the maximum amount of data. This is why larger angles can be recorded even if they were executed for a short time. This represents a good characteristic for the measurement system, given that it represents a higher level of sensitivity.

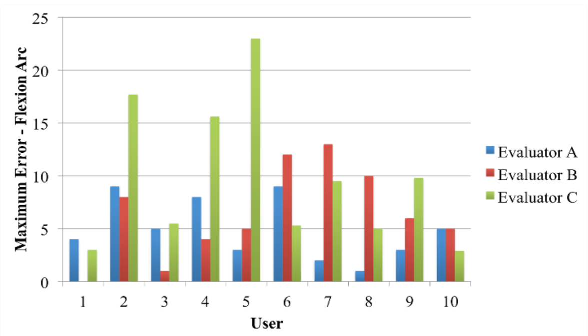

Figure 10. Comparison of measurement error between the evaluators in the two experimental sessions for measuring the maximum shoulder flexion movement arc.

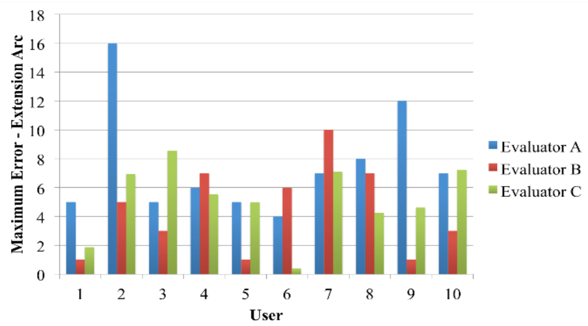

Figure 11. Comparison of errors in the measures taken by the evaluators in the two experimental sessions to measure the maximum range of shoulder extension movement.

In Fig. 11, a comparison of errors in measuring the maximum range of motion in extension, shows that the semi-automatic method used by Evaluator C produced better results on average than the traditional method used by Evaluator A (average of 5.15 vs 8). However, the most consistent data was obtained by Evaluator B using the traditional method (average of 4).

For the case of errors between the measurements captured in the two experimental sessions of the maximum range of abduction motion, the results were very similar in terms of uniformity. The average of evaluators A and B was 11, and the average of evaluator C was 11.05.

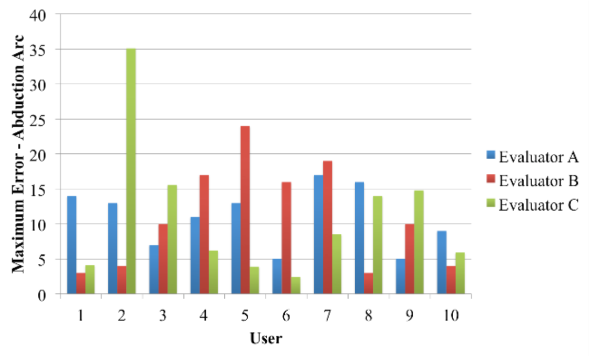

Figure 12. Comparison of the error between the measurements made by the evaluators in the two experimental sessions for measuring the maximum range of motion in shoulder abduction.

The data corresponding to the movement arcs of flexion, extension and abduction are presented in Tables I–III. It can be appreciated that there is a significant difference between the two measurement systems. Note that accuracy exceeds 9 degrees for all three types of movements; therefore, questions about the degree of repeatability of the measures are proposed, taking into account the following aspects:

1) The measures can be increased or decreased at different times as the subjects may expand or reduce the range of motion.
2) The range of motion may vary when multiple measurements are taken.
3) When measuring with the traditional method, the evaluators can correct the subject's posture, which is not done in the semi-automatic method. For example, if a subject mixes adduction and extension movements, it may cause their upper limb to be hidden from the structured light camera, resulting in an erroneous measurement.

TABLE I. Estimation of the Shoulder Flexion Range of Motion Accuracy, Measured with the Semi-automatic Method, Using the Values Obtained with the Goniometer As a Standard

User	Maximum value of flexion arc		
	MTM*	**MSAM****	**Accuracy**
1	171	182	11
2	183	193	10
3	171	175	4
4	171	180	9
5	187	166	21
6	171	178	8
7	162	179	17
8	158	161	4
9	165	170	5
10	165	161	4
Mean	170.3	174.5	9.2

*MTM: Mean traditional method.
**MSAM: Mean semi-automatic method.

TABLE II. ESTIMATION OF THE ACCURACY OF THE SHOULDER EXTENSION ARC MEASUREMENTS, MEASURED USING THE SEMI-AUTOMATIC METHOD, TAKING AS A PATTERN THE VALUES OBTAINED WITH THE GONIOMETER

User	**Maximum value of extension arc**		
	MTM*	**MSAM****	**Accuracy**
1	48	64	16
2	59	65	6
3	41	54	14
4	37	59	22
5	49	34	15
6	65	69	5
7	40	55	15
8	42	42	0
9	37	44	7
10	53	79	27
Mean	46.9	56.4	12.6

*MTM: Mean traditional method.
**MSAM: Mean semi-automatic method.

TABLE III. ESTIMATION OF THE ACCURACY OF THE MEASUREMENTS OF THE SHOULDER ABDUCTION ARC, MEASURED WITH THE SEMI-AUTOMATIC METHOD, TAKING AS STANDARD THE VALUES OBTAINED WITH THE GONIOMETER

User	**Maximum value of abduction arc**		
	MTM*	**MSAM****	**Accuracy**
1	151	167	17
2	163	174	11
3	158	175	18
4	158	180	22
5	152	162	10
6	151	184	32
7	148	170	23
8	151	170	19
9	141	164	23
10	152	177	24
Mean	153	172	20

*MTM: Mean traditional method.
**MSAM: Mean semi-automatic method.

TABLE IV. STATISTICAL DATA OF EACH OF THE TESTS

Test	**Goniometer Value**	**Mean**	**Median**	**Std**	**Variance**	**Maximum**	**Minimum**	**Range**	**Repeatability relative to standard**	**Accuracy**
1	109	114.658	114.601	0.892	0.795	116.604	112.964	3.640	5.727	5.658
2	98	102.240	102.194	0.552	0.304	103.873	101.293	2.580	4.275	4.240
3	83	88.336	88.354	0.557	0.311	89.362	87.063	2.298	5.364	5.336
4	78	76.812	76.406	1.535	2.357	79.592	74.167	5.425	1.935	1.188
5	113	114.327	114.268	0.430	0.185	115.036	113.482	1.554	1.394	1.327
6	103	104.409	104.425	0.217	0.047	104.809	103.959	0.850	1.426	1.409
7	92	92.338	92.403	0.535	0.287	93.240	90.927	2.313	0.631	0.338
8	85	79.192	78.768	1.533	2.351	81.496	76.993	4.503	6.005	5.808
9	112	121.349	121.354	0.276	0.076	122.132	120.182	1.950	9.353	9.349
10	91	108.237	108.392	0.491	0.241	108.938	106.968	1.971	17.244	17.237
11	83	92.549	92.566	0.198	0.039	92.863	91.882	0.980	9.551	9.549
12	71	79.653	79.641	0.256	0.066	80.274	79.026	1.248	8.657	8.653
13	100	99.111	99.304	0.626	0.392	99.936	97.564	2.372	1.086	0.889
14	90	89.076	89.000	0.402	0.162	90.086	87.639	2.447	1.007	0.924
15	82	78.728	78.342	0.763	0.582	79.990	77.866	2.124	3.359	3.272
16	74	68.227	68.224	0.154	0.024	68.584	67.886	0.698	5.776	5.773
17	105	104.607	104.656	0.366	0.134	105.669	103.626	2.043	0.535	0.393
18	94	94.485	94.520	0.397	0.158	95.088	93.675	1.414	0.626	0.485
19	81	84.063	84.032	0.300	0.090	84.798	83.498	1.300	3.078	3.063
20	70	70.886	70.908	0.266	0.071	71.411	69.997	1.415	0.924	0.886

To address the uncertainties about the differences between the measurements generated by the two methods, a second type of experiment was proposed. In thus experiment uniformity in postures was fostered while the measurements were taken, to ensure that the measurements under more similar conditions. The results of this experiment are presented in the next section.

B. Fixed Range of Motion Measurements Were Performed in Experiments to Make the Conditions More Homogeneous

The experiment was conducted on five subjects, three female and two males. The consolidated data of the investigation are presented in Table IV, indicating the mean, median, standard deviation, and variance. It is noteworthy that the dispersion measures indicate a high degree of uniformity in the data. Similarly, statistical indicators such as the maximum, minimum, and range are presented. The repeatability with respect to the pattern was taken as the variance calculated with respect to the value of the measurement using the goniometer. Accuracy is the difference between the mean of the data of each test with respect to the pattern value given by the measurement obtained by the goniometer.

TABLE V. GLOBAL STATISTICAL DATA FROM THE EXPERIMENTS

Statistical Variable	**Mean**	**Maximum**	**Minimum**
Standard Deviation	0.537	1.535	0.154
Variance (Instrument repeatability)	0.434	2.357	0.024
Range	2.156	5.425	0.698
Repeatability relative to standard	4.398	17.244	0.535
Accuracy	4.289	17.237	0.338

Table V overall performance indicators of the semi-automatic method compared to the traditional method. These indicators represent the averages corresponding to Table IV. A low dispersion is clearly observed, indicating high accuracy in the data obtained. The average range is only 2.156 degrees, and the maximum value is only 5.425 degrees. In addition, the semi-automatic method's accuracy was much more favorable than in previous experiments. This is due to the control and uniformity of the conditions when taking the measurements.

The repeatability with respect to the pattern is very similar to accuracy, this is due to the uniformity of the data. It must be stressed that the variance is only 0.434, which equates to the instrument's repeatability, which is very favorable.

IV. Conclusion

The experimental results obtained through the tests that control the amplitude of the movement arcs indicate that the semi-automatic method is an instrument with high repeatability, making it ideal for taking these measurements.

The semi-automatic method provides substantial benefits over the traditional method, as it can take measurements much faster, which not only allows for the study of the amplitude of the movement arcs but also their evolution, which can be an important contribution to medical and physiotherapeutic personnel. However, it has some disadvantages, such as the requirements for accurate movement arcs to avoid the person's body from obstructing the structure light camera while capturing images of upper limb. One possible solution to this limitation is to employ multiple cameras to capture images from different angles or viewpoints.

When carrying out measurement-taking tests with the gauge (goniometer), some factors that can affect the measurement values can be observed; including the position of the instrument in front of the person; for example, if measuring the movement arc of abduction alterations could be generated by placing the instrument since the peripheries of men and women differ due to the shape of the chest, leading to a change in the inclination of the goniometer and therefore affect the measurement

These difficulties during measurement have been reported in previous works [43], for which several strategies have been used in order to minimize them [44, 45]. In the present study, during the measurement with the semi-automatic method, the data was collected using the 3D motion capture system [46–48] in order to minimize the differences caused by the involuntary postural adjustments of the evaluated individuals, which does not apply to traditional measurement; adding to its disadvantages.

The previous considerations and the results of this study support the implementation of Video photogrammetry and semi-automatics techniques, whose methods are based on the use of algorithms [49–51] in the reliable evaluation of the joint movement arcs of the shoulder. These methods are favored not only due to the ease and agility of the procedure, but also due to the clinical application of technology in the movement evaluation and monitoring [52, 53]. The use of this type of device for is much more reliable, since the Typical motion capture system provides accurate kinematic measurement [54]. Other studies [55] have evaluated the reliability of technological applications in measuring shoulder rotation, indicating acceptable reliability compared to traditional goniometry.

In conclusion, the evaluation of a semi-automatic goniometry method was compared with the traditional method, and it was found that the former has acceptable repeatability in shoulder movements compared to the latter.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Carolina Mantilla conducted the investigation, raised the problem and carried out the state of the art. Cesar Peña generated and implemented the algorithm and carried out the verification tests. Gonzalo Moreno took the database of the images and carried out the documentation and its analysis. All authors participated in the writing of the paper. All authors had approved the final version.

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