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ARTICLE INFO

Keywords:
E-Health
Public health
Telerehabilitation
Rehabilitation
Range of motion
MediaPipe

ABSTRACT

The many epidemics that the world is witnessing necessitate the use of telehealth. Developing a website for telerehabilitation follow-up is appealing. Furthermore, the patient benefits financially from the elimination of costly equipment. The major purpose of this paper is to present a telerehabilitation website and to compare an artificial intelligence technique incorporated into the website called MediaPipe to measure range of motion with a universal goniometer and a digital angle ruler. Data was collected from around 50 healthy volunteers with the assistance of physical therapists. The MediaPipe-based shoulder measurement system's reliability is determined. To validate the approach, the 95% limits of agreement and mean difference between the MediaPipe and the two other devices are determined. The results indicate that the MediaPipe is reliable and valid for use in telerehabilitation with the studied movements. The method is then used to monitor a patient with a right patella fracture.

1. Introduction

The World Health Organization estimates that around 15% of the global population is disabled [1]. Some of these people require therapy for some periods of time, while others require it constantly. Telemedicine expands both patients' and medical staff's horizons and capabilities. By using telemedicine, several expenses may be avoided.
Rehabilitation is crucial for patients who have undergone surgery on their lower or upper limbs, or sustained other injuries. Through rehabilitation sessions, the doctor should monitor the patient's gradual improvement by measuring his range of motion using a clinical goniometer. However, this device requires both hands, minimising the doctor's ability to stabilise the joint [2]. Furthermore, a clinician's skills and experience influence the goniometer precision [3]. Another device, called the inclinometer, has been used for its advantages, compared to the goniometer, such as handiness and somewhat better reliability. However, the main disadvantage of the digital inclinometer is that it costs more than a universal goniometer.
Therefore, to remotely measure and follow the progress of a patient's condition, various types of equipments with different functions have been developed, such as sensors like inertial measurement units (IMUs), which include accelerometers, magnetometers, and gyroscopes. The goal of using IMUs is to detect and measure human movements using the remarkable innovations in micro-electromechanical systems, which are lightweight and compact. By incorporating different algorithms for the desired activity, such as rehabilitation, motion tracking, gait analysis, gesture recognition, and handwriting algorithms, IMUs can regroup accelerations, magnetic signals, and angular velocities from human movements [4, 5, 6, 7]. Many research studies have shown the accuracy of wearable IMUs when they are used to make joint angle measurements [8, 9, 10].
The Kinect V1 or V2 devices are also often utilised in telerehabilitation studies [11, 12, 13]. However, the Kinect device is not very accurate. Unlike other technologies for ordinary citizens, its cost is relatively high, and it is not available to everyone. Furthermore, a research study in [14] demonstrated that the Kinect sensor has some limitations when it comes to following some of the exercises involving the lower limbs, especially knee rehabilitation exercises. Thus, it is necessary to find a way for the doctor to remotely check on a patient's health that it works well and does not cost too much.

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There are several examples in the literature of goniometers or digital goniometers being used to compare measurements from sensors or algorithms [15, 16, 17, 18]. Generally, a statistical study should be done to compare the measurement instruments and prove their reliability and validity. Reliability and validity are defined in [19] as follows: the agreement between two efforts to measure the same trait using a maximally similar method is the reliability. The validity is the agreement between two attempts to measure the same trait through maximally different methods.
Çubukçuet et al. [15] provided the reliability and validity of the Kinect V2 device for shoulder motions, comparing it with a goniometer and an inclinometer. Additionally, Wochatz et al. [16] provided the reliability and validity of the Kinect for lower-limb movements. Vafadar et al. [20] studied the inter-rater and intra-rater reliability and validity of a laser pointer, an inclinometer, and a goniometer. Abd Elrahim et al. [21] investigated the inter-rater and intra-rater reliability of Kinova software when it is used to measure the shoulder joint ROM in healthy individuals. This software is a video-based method for measuring the range of motion of joints using a virtual goniometer. By considering the above studies, we aim to find more effective solutions based on cutting-edge technologies that are available to the majority of people at a lower cost.
In this research study, we focused on using the MediaPipe technique [22] in the telerehabilitation field to measure the range of motion. Through our in-depth research, we found that, so far, no studies have been conducted to confirm the reliability and validity of the MediaPipe technique in the measurement of the ROM. This is why we decided first to study the reliability of this technique and compare it with a goniometer and an angle ruler. The MediaPipe technique has been used in various research studies, such as those concerning yoga movements [23] and rehabilitation [24]. One of the most important features of the MediaPipe technique is that it can smooth out any noise from pose prediction or classification by applying an exponential moving average (EMA). By doing this, we can obtain the nearest pose cluster, calculate a probability for each of them, and utilise them for smoothing over time. Different methods have been used to filter raw data in object tracking, such as those of [25] and [26].
The main contributions of this paper are the following:

- **Investigation of the reliability and validity of MediaPipe-based measurements.**
- **The discussion of MediaPipe's contribution to telerehabilitation by validating it through real patient cases.**

The rest of the paper is structured as follows. Section 2 introduces the three methods used to measure the proposed motions. This section is divided into two subsections, where the first one introduces the technique of MediaPipe, the goniometer, and the angle ruler. The second subsection presents the data for the shoulder ROM, and a the statistical analysis is provided. Section 3 discusses the reliability and validity of MediaPipe. In Section 4, the main goal is to present the contribution of MediaPipe to telerehabilitation, with a patient case study. Section 5 is a discussion of the technique and the project. Section 6 concludes the paper and introduces some future directions.

2. Methods and Data of measuring ROMs

2.1. Technique and instruments used in measuring the range of motion

In this research project, a total of 50 volunteers have participated; their ages range from 21 to 42. Most of the data were taken at the University of Skikda. All participants were measured using three methods: MediaPipe with a camera on a computer, Dell Intel(R) Core(TM) i5-4310U CPU @ 2.00GHz, 2.60 GHz, and 4.00 GB RAM. The second instrument is a clinical goniometer (figure 1). The third is a digital instrument called Angle Ruler 50, a 360° digital protractor 2×50 cm ADA (see figure 1). The measurement accuracy is about 0,3° , power: 3V, $1 \times$ CR 2032. Data are visualized on the built-in LCD digital display.
This study measures four ranges of motion, shoulder abduction, adduction, flexion, and extension. Before beginning to measure the movements, we obtained consent from all volunteers to publish their data in this research. We had a physical therapist explain the method to each individual and take measurements. We first started by measuring the four movements with MediaPipe in three repetitions. This procedure aims to calculate the intraclass correlation coefficient (ICC) to prove the reliability of the technique. The physiotherapist did just one measurement with the goniometer and the angle ruler.

2.1.1. MediaPipe pose estimation technique

MediaPipe is a framework developed by Google for machine learning applications [22]. It predicts the location of 33 pose landmarks (see figure 2). This technique can forecast a full-body segmentation mask depicted as a two-class

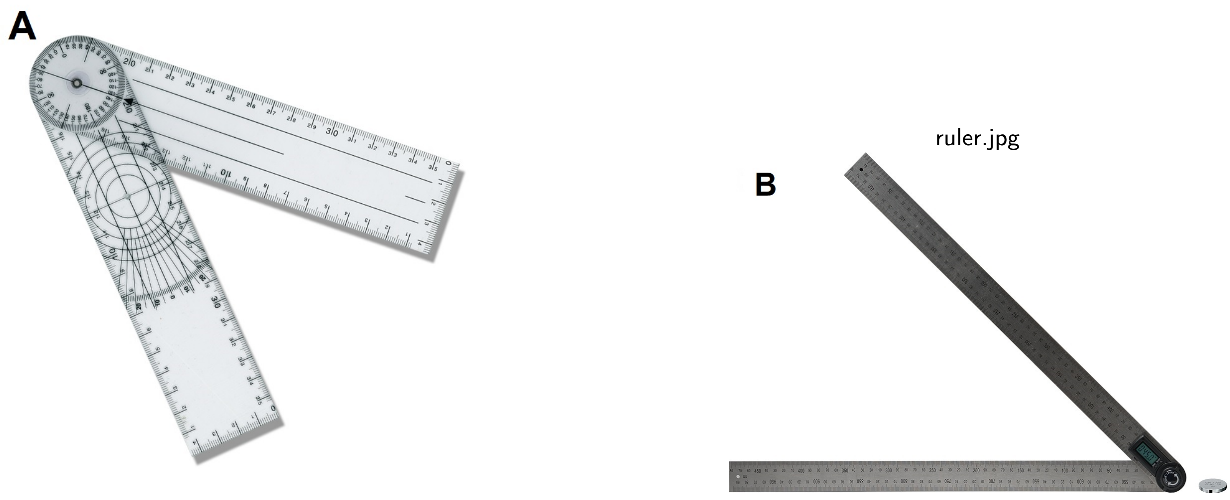


Figure 1: Instruments used in the measurement of ROM:A- Goniometer, B- Angle ruler.

segmentation (human or background). Using the MediaPipe framework, inference models like TensorFlow and TFLite, as well as multimedia processing functions, can be constructed. With BlazePose, MediaPipe infers 33 3D landmarks on the whole body from RGB video frames. Its library output holds the coordinates of the user's major basis in the image.

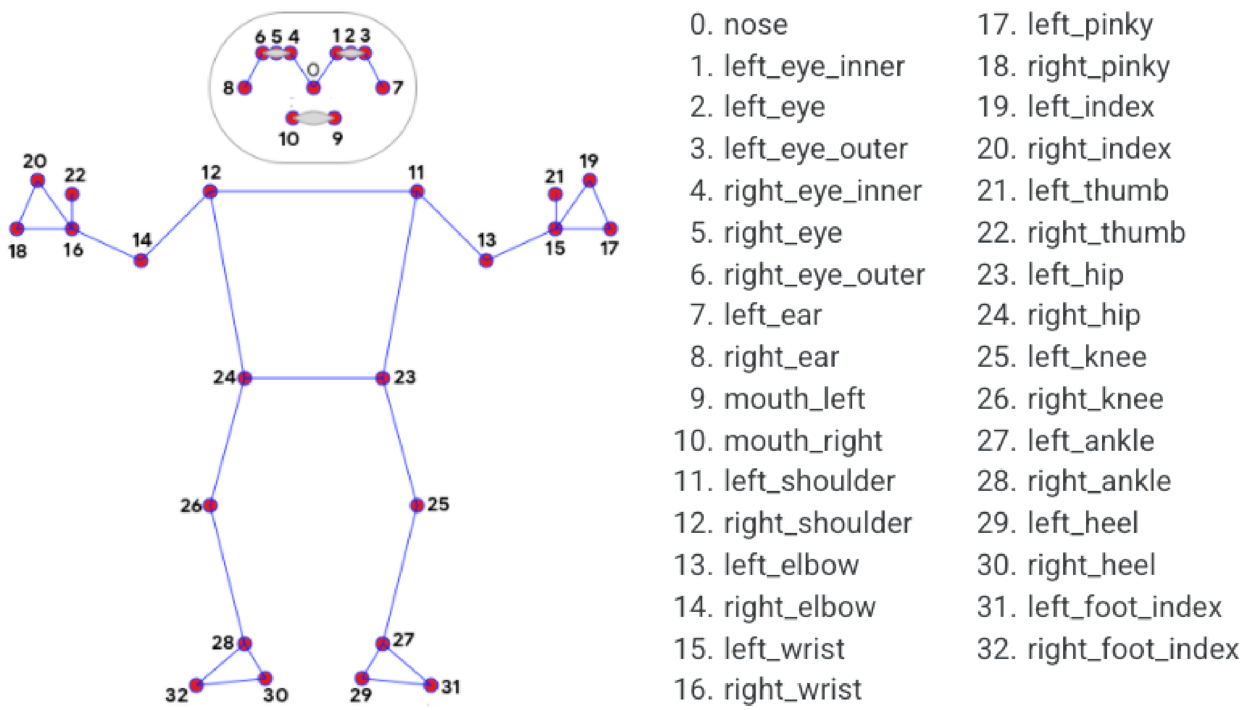


Figure 2: BlazePose model 33 human Poses [27].

A function is programmed to get the data. Then, this function calculates the angles at each human body joint. The angle made between the two lines is calculated by using analytic geometry. For example, we have three points (show figure 3), $A(x1,y1)$, $B(x2,y2)$, and $C(x3,y3)$. We suggest that AB and BC as skeletal structures, or two bones. The intersection between the lines AB and BC is on point B. The angle between AB and BC can be determined as follows: Slope of AB is:

$$d1 = (y2 - y1)/(x2 - x1). \tag{1}$$

BC slope is:

$$d2 = (y3 - y2)/(x3 - x2). \tag{2}$$

Now, we can determine the angle between AB and BC :

$$tan\theta = (d1 - d2)/(1 + d1.d2). \tag{3}$$

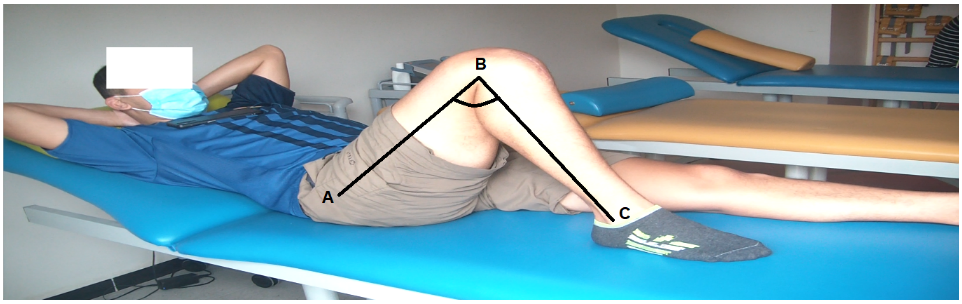


Figure 3: Angle joint calculation.

Measurement

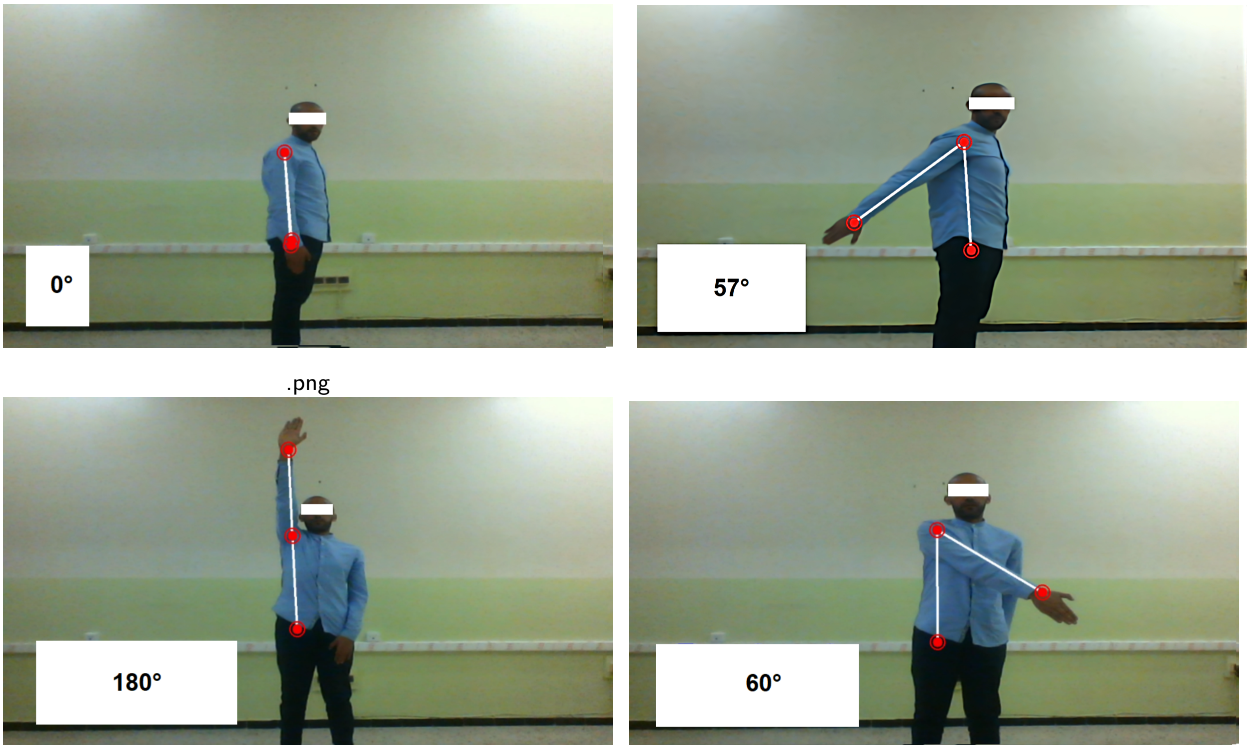


Figure 4: Some pose estimation.

2.2. Statistical analysis

A physiotherapist was responsible for interacting with the participants and taking the readings from the clinical goniometer and the angle ruler. Measurements were made by the three methods. The volunteers did the proposed movements playfully. The results obtained are compared with the normal interval values of [28], which shows that all the results are on the normal average.

To obtain the statistical analysis, IBM SPSS Statistics version 26 was utilized. An ICC was applied to show if the MediaPipe is reliable. According to [29, 30, 31, 32, 33], the ICC was assessed as follows: between 0.81 and 1.0 is "very good or excellent", and good if the result is inside the interval of 0.61 to 0.80. "Moderate" if it is between 0,41 and 0,60, and "fair" if the value is between 0,21 and 0,40. Finally, it is "poor" if it is below 0.20. The standard error of the measurement (SEM) and the minimal detectable change (MDC) are calculated to get the absolute reliability, as shown in the two next equations [34, 35] :

$$SEM = StDev.\sqrt{1 - ICC} \tag{4}$$

$$MDC = SEM.\sqrt{2} \times 1.96 \tag{5}$$

The StDev indicates standard deviation. Then, to prove MediaPipe validity, Bland-Altman analysis [36] is effectuated. Limits of agreement (LOA) and mean bias metrics are calculated to evaluate the absolute accuracy of MediaPipe over the goniometer and the digital ADA.

3. Results

Figure 5 compares the ROM value results of the shoulder abduction, adduction, extension, and flexion, using the three methods. Different colors indicate each method of visualizing the differences. Figures 6,7, and 8 indicate the

Table 1
Data of four shoulder motions obtained using universal goniometer, angle ruler and MediaPipe.

Movement	Meth	Mean	SE Mean	StDev	Min	Q1	Med	Q3	Max
Abduction	Go	177.76°	0.48°	3.41°	160°	177.5°	179°	180°	180°
	AR	177.86°	0.45°	3.20°	161°	177.07°	178.95°	179.65°	180°
	Me	177,20°	0,49°	3,49°	160°	177°	178,50°	179°	180°
Flexion	Go	169.12°	0.88°	6.28°	155°	163.75°	174°	174°	180°
	AR	169.54°	0.89°	6.30°	157.50°	163.87°	170°	175.10°	179.7°
	Me	169,40°	0,93°	6,61°	155°	165°	170°	176°	180°
Adduction	Go	64.50°	0.94°	6.66°	51.00°	59.75°	60°	64°	75.00°
	AR	64.95°	0.95°	6.71°	51.20°	60.25°	64.20°	70°	75.10°
	Me	64.40°	0.95°	6.76°	50.00°	60°	64°	70°	75.00°
Extension	Go	56.89°	0.49°	3.51°	45.00°	55.00°	58.50°	59.00°	60.00°
	AR	57.24°	0.51°	3.63°	44.80°	56.10°	58.50°	60.00°	60.90°
	Me	56.88°	0.51°	3.63°	45.00°	55.00°	58.20°	60.00°	60.00°

Abbreviation : Meth : method, Go : clinical goniometer, AR : Angle Ruler, Me : MediaPipe, SE Mean :standard error of the mean, StDev : Standard deviation, Min : minimum, Med : median, Max : maximum.

Table 2
Reliability results of the MediaPipe based measurement system.

	ICC	StDev	SEM	MDC
Abduction	0.968	2.11°	0.377°	1.046°
Adduction	0.99	5.778°	0.5778°	1.601°
Extension	0.99	4.296°	0.4296°	1.190°
Flexion	0.992	6.725°	0.6725°	1.864°

histogram graphics to show the distribution of the active range of motion of the shoulder movements cited previously. The black curves represent the Gaussian distribution, or the normal distribution, which is a probability distribution that is symmetric about the mean. As indicated, there is no significant difference between the three methods, and this is what Table 1 shows.

3.1. Reliability results

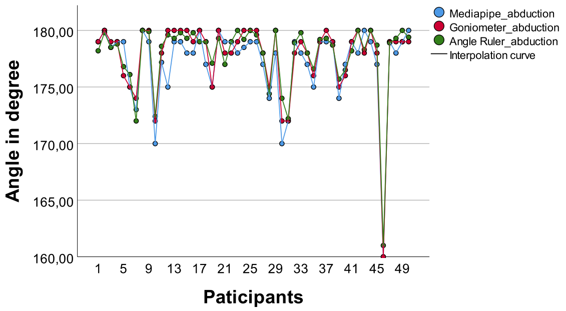
Firstly, we did a test of the reliability of MediaPipe. All participants were measured at three different times. The MediaPipe reliability results of shoulder motion pose are noted in Table 2. It includes the pose of the proposed movements with Mean, StDev, SEM, MDC, and ICC values. Through the ICC, the presented AI method has excellent reliability because all the results are > 0.81 in the proposed movements.

3.2. Validity results

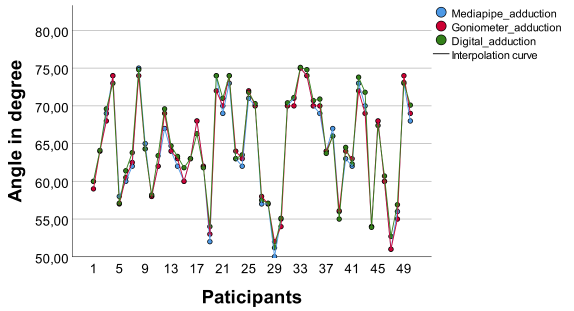
To get the validity of the MediaPipe, a 95% limit of agreement (LOA) between MediaPipe-based measurement and the two other instruments calculated, is calculated as follows:

$$Upper\ limit = Mean(bias) + 1,96\ .\ StDev \tag{6}$$

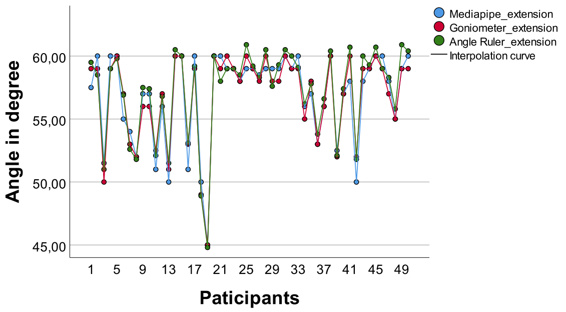
$$Lower\ limit = Mean(bias) - 1,96\ .\ StDev \tag{7}$$



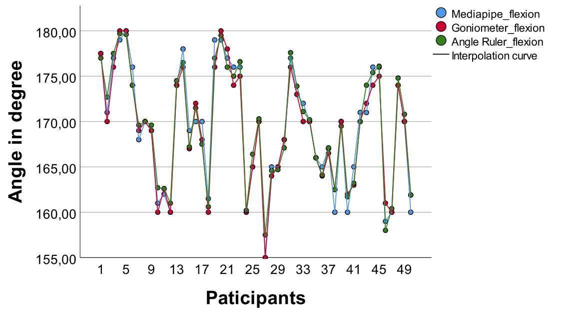
(a) Comparison of shoulder abduction with three techniques.



(b) Comparison of shoulder adduction with three techniques.



(c) Comparison of shoulder extension with three techniques.



(d) Comparison of shoulder flexion with three techniques.

Figure 5: Comparison of the three methods of measurement in studied motions.

Table 3
Bland-Altman analysis results of shoulder joint data acquired utilizing Universal goniometer, angle ruler and MediaPipe.

	Goniometer vs MediaPipe		Angle ruler vs MediaPipe	
ROM	Mean bias	95% LOA	Mean bias	95% LOA
Shoulder abduction	-0,55°	-2,9436° to 1,8308°	-0,6604°	-3,2865° to 1,9657°
Shoulder adduction	-0,108°	-1,774° to 1,558°	-0,552°	-2,44° to 1,34°
Shoulder extension	-0,01°	-1,8916° to 1,87°	-0,36°	-2,4327° to 1,7127°
Shoulder flexion	-0,14°	-2,5998° to 2,3198°	-0,14°	-2,5998° to 2,3198°

The results of Bland-Altman plots comparing the two instruments with the MediaPipe are obtained by the MediaPipe presented Table 3. In the shoulder extension, the mean differences of the UG from the MediaPipe technique were -0.01°, -0,108° in the adduction. -0,55° in the abduction and -0,14° in the flexion. In the extension, the mean differences of the angle ruler from the MediaPipe technique were -0.36°. -0,552° in the adduction, -0,6604° in the abduction, and -0,14° in the flexion. As shown in the Figure 9, the differences in the studied pose angles acquired by the two measurement methods are not distributed in a systematic way. However, a random distribution for all the studied motions. These values fall within a narrow range, whether comparing the MediaPipe with the goniometer or the MediaPipe with an angle ruler. So, they indicate a generally superior agreement. According to [36], the validity analysis gives good results for all proposed motion poses.

This study proved that there is no difference in calculating some ROMs utilizing the three different methods. The proposed new technology could help physiotherapists with telerehabilitation and be useful for clinical rehabilitation.

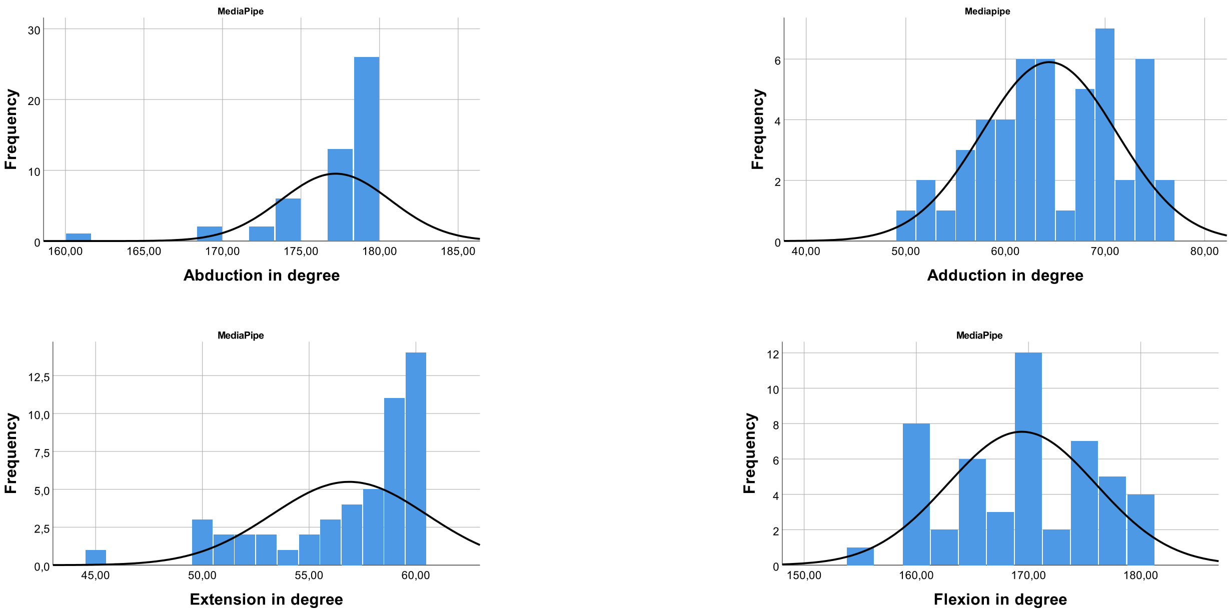


Figure 6: Shoulder ROMs frequencies with MediaPipe method of measurement.

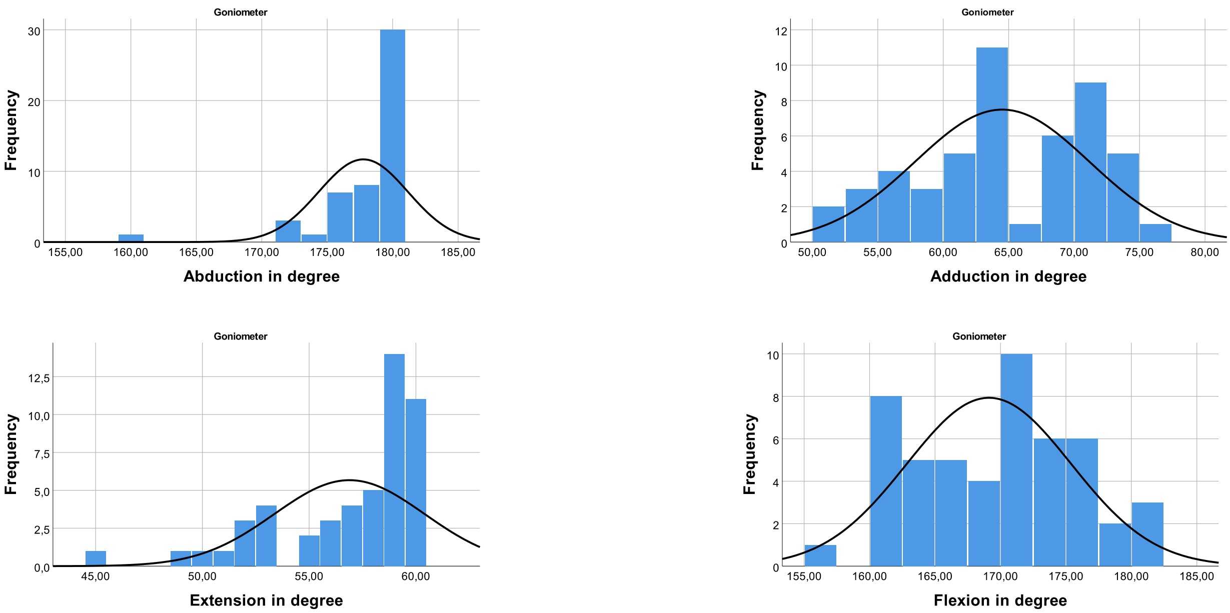


Figure 7: Shoulder ROMs frequencies with goniometer method of measurement.

4. MediaPipe's contribution to telerehabilitation

4.1. Site web overview

The website has been created and developed for several reasons and factors. What the world experienced during the COVID-19 period and the variants that emerged like Delta and Omicron need to be considered in future scientific research and work to find practical solutions that help the patient during epidemics and crises in particular, and in

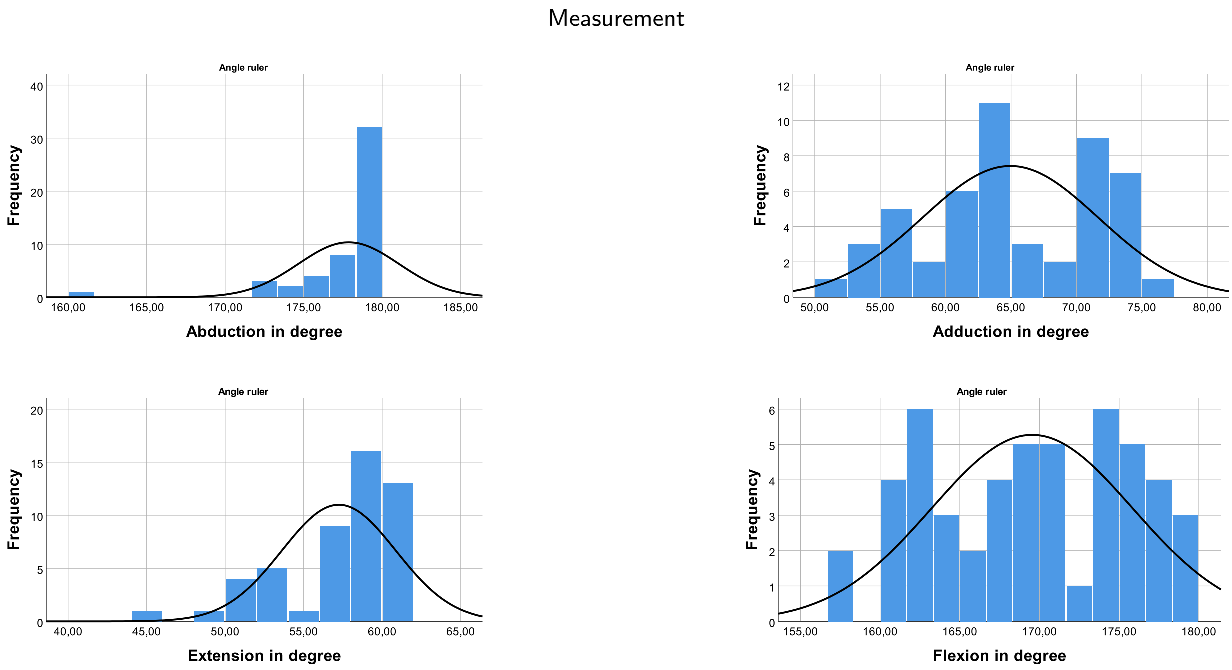


Figure 8: Shoulder ROMs frequencies with angle ruler method of measurement.

general on all days. In addition, the patient often suffers from difficulty moving. Therefore, it is recommended to do rehabilitation exercises at home, and this is done by monitoring the patient via the site and remotely and accurately by watching the data in real-time. The third reason is to avoid transportation costs and other related costs. Whereas, in third-world countries, there is a difficulty in moving with the scarcity of transportation and the concentration of major hospitals and health centers in major cities. It makes it difficult for those living in villages and rural areas. For example, here in Algeria, most of the area is desert, and moving around is tiring, exhausting, and expensive. In addition to the scarcity of transportation, especially in desert areas, the patient must travel more than 200 km to reach the nearest hospital or health center. Another critical factor is hospital overcrowding, as the patient often waits more than a month to get the earliest appointment. In addition to all these reasons and factors, wearable sensors or Kinect sensors can be dispensed with through the website and by the method used. They are the most widely used equipment in telerehabilitation and thus save costs. In Algeria, this equipment is too expensive for most people to buy because it costs more than the basic wage of the average worker.

The proposed website focuses on artificial intelligence techniques to visualize the angles of the desired joints of the human body in real-time. Facilitating the use of the website is the first objective. The platform includes two stations; the first is for the patient, and the second is for the physician or doctor. The accounts are created by an admin (show figure 10). For the privacy of the data, each patient and doctor has an e-mail and password.

The doctor can schedule appointments and patients involved in rehabilitation sessions. The manager does all the technical procedures. Communication between the doctor and the patient is done via the Internet. To facilitate the process for the patient, we relied on the simplicity of the way to use the site. Because we know we are dealing with different segments of society. In addition, there is a page on the site that helps explain how to use it to the patient. Also, there are no complications on the patient page; just two buttons to choose if the rehabilitation is in the lower or upper extremities, and a button to enter the meeting with the doctor (show figure 11).

When the meeting begins and after the conversations, the patient must stand in front of the computer or the phone, two or three meters away, and start exercising. Here the doctor can monitor the patient from a distance and see the values of the ROM in real time. On the screen and through the curve that shows the values for each frame. Then, the doctor can record the values, keep them, and compare them with the values of the upcoming sessions. After the meeting, the data can be kept in many formats; XLS, PDF document, CSV, JPEG, or PNG image (show figure 12).

Python and node.js were used as programming language, and Nginx 1.10.3 was utilized as the web server and inverse proxy. PostgreSQL is utilized as the primary data store for the web. Select 2, Moment.js 2.17.1, jQuery UI

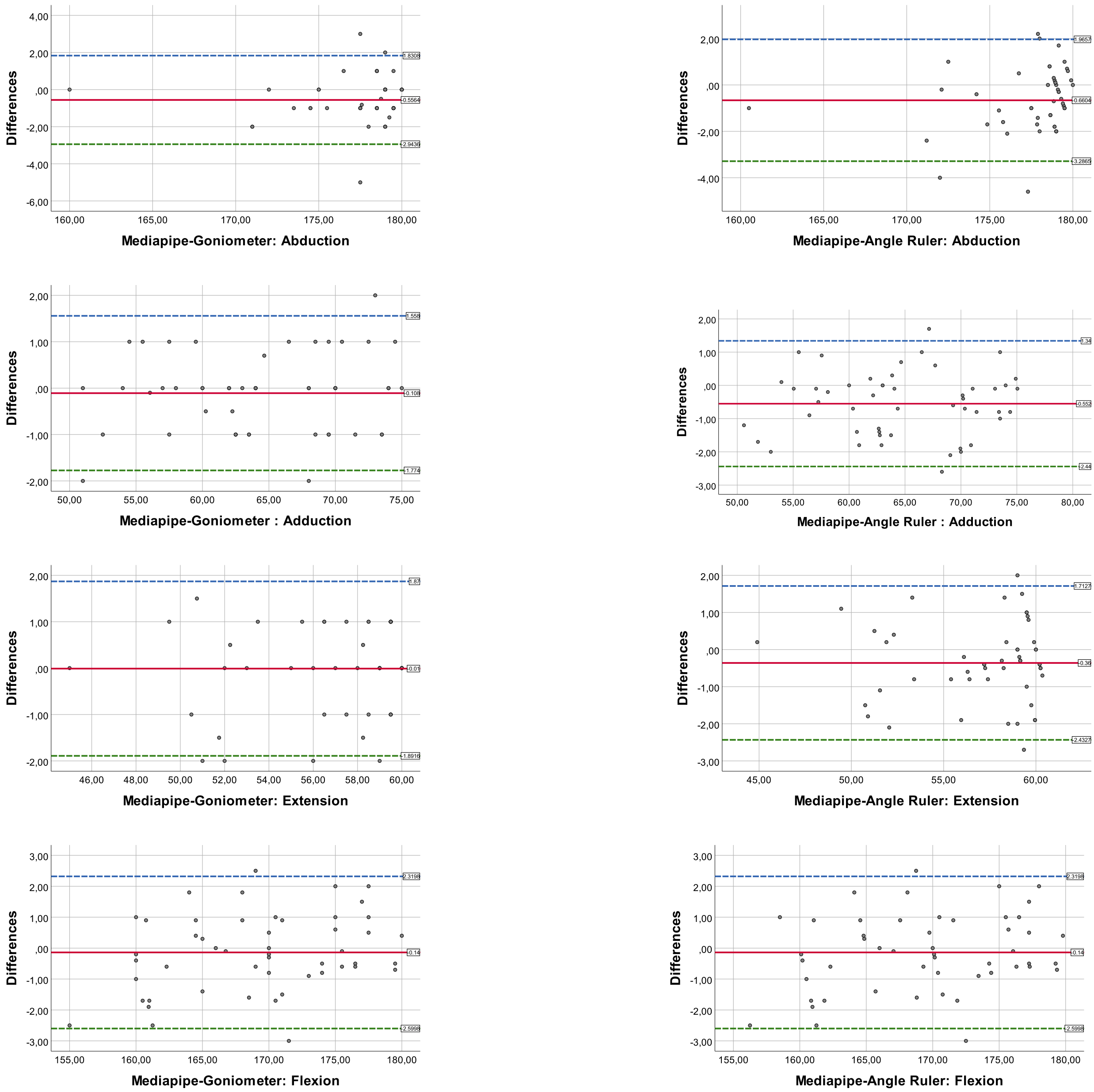


Figure 9: Bland-Altman plots a comparison between MediaPipe and UG and MediaPipe and an AR.

1.11.4, jQuery. 1.11.1 were used as libraries in JavaScript. To track and control the range of motion, a library called MediaPipe was integrated with the website.

4.2. Patient case study

A physical therapist often uses a goniometer to measure ROM and pursue a patient's condition in rehabilitation sessions. In this case, the doctor is often with the patient. Advanced tools such as wearable sensors or Kinect are required in telerehabilitation, but they are often expensive. In this research, a website is proposed. The MediaPipe library is integrated to show the ROM's value in real-time. Through this technique and from the data of several healthy people, it has been observed that a healthy person can reach 20° of flexion. The patient finds it difficult to do the flexion, and this is why he needs rehabilitation sessions.

Measurement

patient.jpg

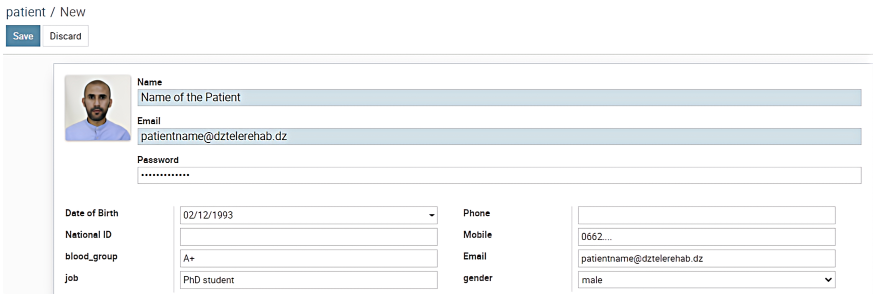


Figure 10: Registration for patient account.

station.jpg

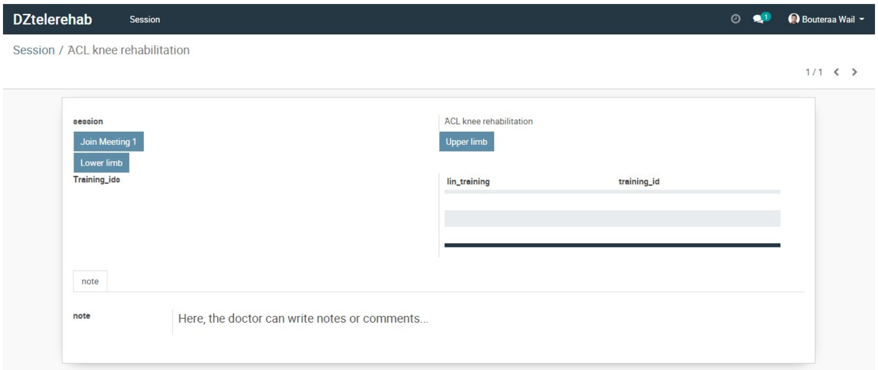


Figure 11: Patient station view.

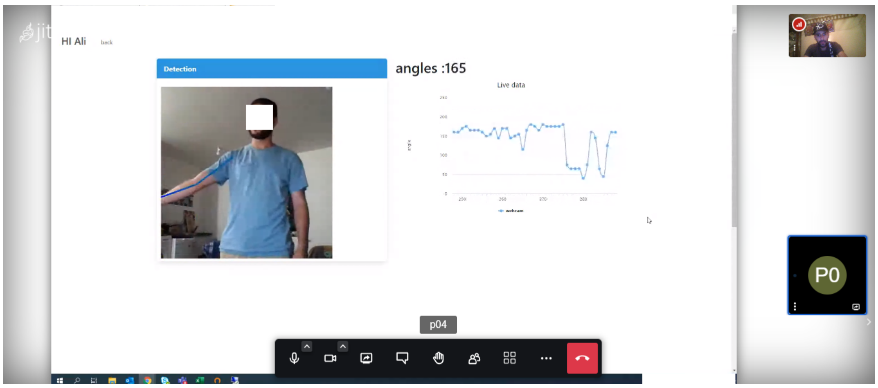


Figure 12: Physiotherapist view during the session.

Before starting to continue the rehabilitation process, approval was first obtained from the doctors in order to help and take their advice and directions. Also, the patient signed our request to allow us to take the photos, videos, and data needed for this study.

This study followed a 21-year-old patient injured in a traffic accident. He was operated on for a fractured right kneecap. His first day of rehabilitation took place on December 30, 2021. The blue graph (figure 13) represents the data of a healthy person. We use his data to facilitate the comparison between the healthy subject and the patient. Furthermore, to clarify the progress of the patient. From the first curve, we can see that the patient has difficulty bending his knee. The data shows that the flexion value is 142°, the lowest value. After five days, we noticed no noticeable improvement in the patient, and that was due to the pain he was in somehow; he had not adopted and was unresponsive to rehabilitation exercises, which is what is observed through the curve (Record 2). On January 19,2022, we noticed a remarkable development in the bending process, and it was because the patient was attending massage and rehabilitation sessions even at home, which helped him achieve more degrees in the flexion "about 54°". In the fourth recording, a noticeable improvement and speed in the bending process were noticed compared to previous sessions. Here, the patient begins to reach essential stages of recovery, where he performs the flexion-extension process smoothly and at considerable speed. Here, the minimal value of the flexion is about 67°. Then (Record 5), the patient reached about 42°, which means a significant improvement. In the last session, the flexion reached 39°. It was also noted that the pain had gone down a lot after the rehabilitation process. Finally, the technology helped the physiotherapist monitor the patient's condition remotely. Both sides strongly recommend this, and many doctors are interested in remote rehabilitation because it will make the operation much easier for the patient and cut down on the number of people in hospitals and the time it takes for patients to get to their appointments.

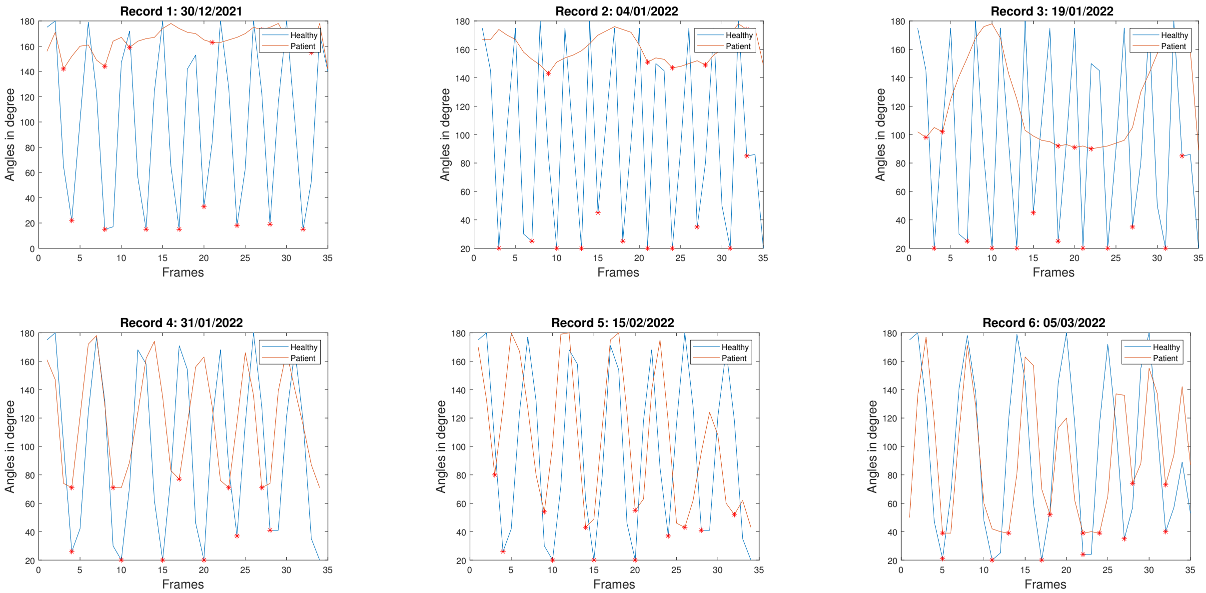


Figure 13: RoM data of knee flexion extension of patient in six records

Table 4
MediaPipe ICC results compared to other devices and techniques.

	Mediapipe	UG	Kinect
Movement	ICC	ICC	ICC
Abduction	0.968	from 0.58 to 0.99 [38, 39, 40, 41]	0.86-0.98 [15]
Adduction	0.99	0.98[42]	0.59 [17]
Extension	0.99	0.91[42]	0.62 [15, 43, 44]
Flexion	0.992	0.53 to 0.96 [39, 40, 41]	0.85-0.99 [15, 43, 44]

5. Discussion

The range of motion evaluation is a crucial component of musculoskeletal exploration [37]. A goniometer is often the most commonly used method by kinetherapists. But its use is manual only, and with the development of telerehabilitation techniques, it is better to search for modern methods that are more accurate and comfortable for the patient.

This study reports the reliability and validity of the MediaPipe-based system for measuring four active shoulder ranges of motion. Compared with the clinical goniometer and the Kinect results cited in Table 4, and with the results obtained with MediaPipe, we can say that the MediaPipe technique has excellent reliability and is relatively accurate.

The rehabilitation process often takes weeks. Through the proposed website, the doctor can monitor the condition of his patient remotely. It can also guide and correct the position. Often, the patient feels more comfortable doing rehabilitation at home than moving to a hospital or rehabilitation center. Also, through this work, the patient avoids many expenses such as transportation and other costs. It also avoids the trouble of traveling, as it desperately needs rest. The proposed technique is also inexpensive, and it is coughed up in terms of use. The most important point that we took into consideration is the protection of patient data, because, as we know, patient data is very sensitive and medical privacy is important. That is why we protect the data and accounts of all patients.

There are some limitations that must be taken into consideration when we are doing the experiments. The most prominent of these is the misuse of technology by a segment of society, especially elderly people. It requires foreign intervention. The proposed technique has so far only been programmed to detect one person per frame. It may not be appropriate to use it when there are multiple people in the image frames.

From what we have noticed in our experience, we must choose the best position in front of the camera for good detection. An arbitrary position may have an effect on the pose estimation. Moreover, it is better to work with the application in good lighting conditions because experiments show noise introduction due to lighting conditions.

One of the main drawbacks is the instability of the internet. That is why we proposed another solution, which is to record the session through the development of a WebApp and then send the results to the doctor, who will in turn evaluate the results and send his feedback to the patient. Another limitation that can be added as future work is how these experimental results correlate to more complex movement types, for example, reach-to-grasp movements.

6. Conclusion

The goal of this article is to test the reliability of using this novel technique in telerehabilitation precisely. The ICC results demonstrate that the MediaPipe technique is excellent for studied motions. The 95% LOA results of the presented rehabilitation exercises concluded that the MediaPipe provides near results to the two other instruments. As stated by Bland-Altman analysis results, it is evident that the presented MediaPipe technique is valid for use in telerehabilitation.

Furthermore, this study presents a website for telerehabilitation to control rehabilitation at a distance using the technique of MediaPipe, the progress of which is an active range of motion (AROM) of patients in real-time. The results showed that it is an ideal idea to develop a home-based rehabilitation system using just a computer or tablet, so the cost is less than using a wearable sensor or Kinect. In the future, we plan to study and test the technique in different situations with different types of complex movement and arbitrary orientation.

Ethics approval and consent to participate

No indication of ethics is given.

Consent for publication

Permission has been taken from all patients and participants in this research project to share their data or photographs.

Availability of data and materials

The data that support the findings of this study are available upon request from the authors.

Competing interests

The authors have no competing interests to declare that are relevant to the content of this article.

Authors' contributions

All authors have been personally and actively involved in substantial work leading to the paper and will take public responsibility for its content.

Acknowledgments

The authors thank all the patients and medical staff for participating in this study. It is noted that this research was supported by the Directorate General for Scientific Research and Technological Development (DGRSDT) in Algeria (Project PRFU No. A01L09UN210120220001).

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