Evaluating Lower Limb Joint Flexion by Computerized Visual Tracking System and Compared with Electrogoniometer and Universal Goniometer

Chee Chin Lim[1], Marwan Affandi[2], Shafriza Nisha Basah[1] and Mohamad Yazid Din[3]
[1]Universiti Malaysia Perlis, Perlis, Malaysia.
[2]Medan Institute of Technology, Sumatera Utara, Indonesia.
[3]Hospital Tuanku Fauziah, Perlis, Malaysia.
cheechin10@gmail.com

***Abstract*—The lower limb joint's range of motion (ROM) is an important clinical parameter used in diagnosing the severity level of lower limb joint injury. Along with the use of mechanical devices such as goniometer or electrogoniometer, motion capture and visual tracking has been increasingly deployed to aid the lower limb joint diagnosis. The universal goniometer can simply measure the joint angles. However, it has some limitations on allowing the clinician to analyze the ROM at the gate and track the lower limb joint. Motion capture devices are mainly used to analyze the patient's joint flexion and assess the condition of the joints and bones. This study has used the visual tracking system (VTS), electrogoniometer (EGM) and universal goniometer (UGM) methods to examine the range of motion of 20 healthy subject volunteers. The results of three methods have been compared and discussed. The ROM result shows that VTS have the smallest SEM with averaged of 1.49 compared to EGM 3.41 and UGM 1.53. Thus, VTS give the high accurate in averaged lower limb flexion measurement. The result of joint flexion shows that left and right limb joint are similar for the healthy subject.**

***Index Terms*—Intraclass Correlation (ICC); Range of Motion (ROM).**

I. INTRODUCTION

Lower limb injuries are common problems experienced by many people from all ages due to various causes such from falling, motor-vehicle accidents, sports accidents and arthritis. These injuries can cause huge economic losses since the treatment is often expensive and reduce productivity because the patients often undergo long rehabilitation process before recovering from the illness. Doctors will diagnose the severity level of the injury through range of motion (ROM) measurement of the lower limb joint. Accurate ROM of the lower limb joint is important as a doctor can assess properly whether the patient should have an operation or just get medication to relieve the pain. Currently, there are many methods used to do the measurements such as using Electrogoniometer (EGM), Universal goniometer (UGM) and Visual Tracking System (VTS). UGM are most popular among the doctors since they are inexpensive and easy to use. Research on VTS is flourishing since the method is found to offer many advantages compared to EGM and UGM. VTS can be markerless or use markers to detect the motion. In this paper lower limb joint flexion will be evaluated by using VTS with markers, EGM and UGM.

The objective of the present study was to evaluate the movements of ankle plantarflexion, knee flexion and hip flexion in healthy young individuals through statistical distribution of the data quality of the three measurement systems. Second, the significant differences among the three measurement systems were determined by comparing those systems. The similarity of the left and right joint flexion is determined by the comparison between three measurement systems.

II. LITERATURE REVIEW

The principle theory of goniometry is used for measuring human joint flexibility by expressing in degrees the ROM in a joint in clinically [1], [2]. It can be used to measure both active and passive ROM. There are many instrument is developed based on this theory for ROM measurement such as universal goniometer and electrogoniometer. Goniometer is an instrument to measure joint movements and angles [3]. It is used to measure local (internal) joint angles during human movement by attaching it across two or more joint segments. The corresponding angular output can then be used for quantitative clinical evaluation. The development of goniometry theory is goes for digital application such as electrogoniometer [4], [5].

Furthermore, the human movements were captured by one or multiple cameras to track human motion in motion capture system. The human motion capture systems can be divided into two categories to track body parts: Marker-based system (MBS) and Marker-less system (MLS) [6], [7]. In the MLS, there are no markers used to place on the human subjects. Without wearing markers on subjects, it is a rather inexpensive method [8]. However, it has disadvantages such as lower accuracy and slower updates rates than MBS [6]. In order to have better accuracy, multiple camera is used simultaneously see [9], [10]. Since marker-less motion capture is achieved by applying advanced image analysis on regular video frames [8], the algorithm (e.g. stereo triangulation) will be difficult to construct. This is because multiple cameras must be synchronized, making its processing lengthy and its algorithms more complicated.

Due to the aforementioned disadvantages of the conventional method such as UGM, all the needs cannot be fulfilled satisfactorily. The UGM is not very accurate and efficient because it depends on the skill of users. Furthermore, it is also not so user-friendly. The only one advantage of the goniometer is low cost. Therefore, there is a need to develop a system that can fulfil the clinical need. Thus, an inexpensive and accurate colour marker based visual tracking system is proposed for the assessment analysis of the lower limb joint ROM. This research used markers for human motion tracking. There are several advantages offered by our proposed VTS. The markers used in this research do not hinder natural movements because they are very light. When the markers have been placed on the correct position on a patient's body, the possibility of the markers to peel off or fall easily is very small unless the patient sweats very profusely. Our markers can be placed very quickly on a patient's body and can also be replaced without any difficulty. So, time needed to setup the system is not very significant as in the nest section. Algorithm of marker-based system is less complicated compared to markerless' one and processing time is also less.

III. METHODS

A. Subjects

Twenty healthy subjects matched for ten females and ten males were taken to participate in this study. The statistics of the male participants were as follow: mean age 27.7 ± 3.33 years, mean mass 70.2 ± 7.25 kilograms and mean height 1.68 ± 0.05 meters while for the female participants mean age was 25.8 ± 3.29 years, mean mass 54.3 ± 6.2 kilograms and mean height 159.2 ± 0.07 meters. None of the individuals had presented any reports of pain in their knees, ankles or hip joints over the past year. They had no histories of leg injuries or equilibrium disorders, no real or apparent discrepancies in leg length, and no knee or foot postural alterations. The individuals selected were informed about the objectives of the study, and signed a form giving their informed consent to the procedures. The project had been approved by the Medical Research Ethics Committee of Malaysia Health of Ministry (Reference No: KKM/NIHSEC/P14-957). Even the number of subjects is small, they are assumed to have represented the population because the statistics of general population in Malaysia for the ages from 25 to 30 are more or less the same as found from the study.

B. Equipment

The lower limb joint flexion angles were recorded by visual tracking system (VTS), electrogoniometer (EGM) and universal goniometer (UGM). Video was recorded with a Kinect camera. The EGM recordings were carried out with an EGM and an acquisition unit (SG110 and DataLog, respectively, from Biometrics Ltd., Gwent, UK). The UGM recording was carried out by observing the goniometer rulers arm placed on the knee segment.

C. Visual Tracking System

The visual tracking system was designed based on the image processing and color based tracking techniques as shown in Figure 1. The GUI of the system was designed and initialized for data acquisition. The RGB image video was recorded by a Kinect camera with 30 fps. The recorded video underwent image pre-processing of image subtraction, image median filtering, image thresholding and image noise removing. The marker color was be tracked by image blob analysis. The coordinates of all points A, B and C on the lower limb joint are tracked, and then the angle between AB and BC can be determined as in Figure 2. Angle of Lower limb joint was evaluated by using cosine law with the three tracking point on the bony landmark. The changes of the angle motion of the lower limb joint will be tracked and calculated and displayed as shown in Figure 2.

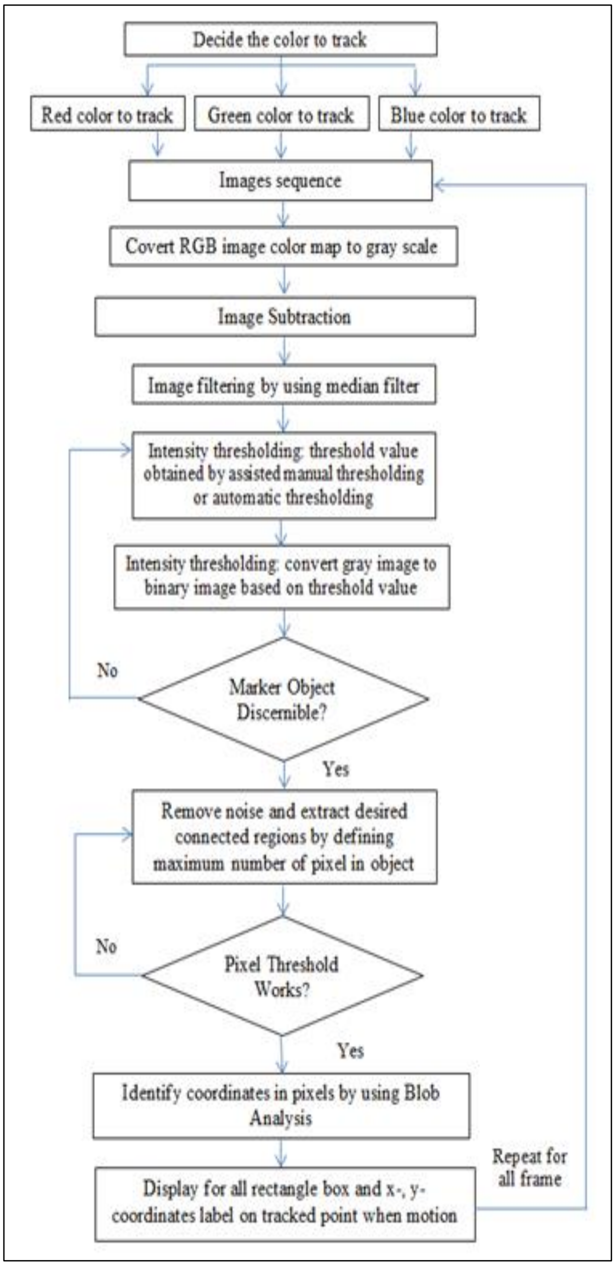


Figure 1: Flowchart of procedures for Visual Tracking System

A Kinect camera was placed opposite and parallel to the subject about 50 cm to 100 cm apart from each other [11], so that it could correctly record all of the markers on the subjects during the joint movements. The optimum performance of the VTS should set at threshold value at 0.2 and maximum number of pixel in object at 30 pixels in the environment of 80 lux light intensity and 80 cm distance camera with subjects, and camera elevation at zero degrees [12]. To evaluate joint flexion movement, color markers (13 mm diameter) were attached to the bony landmark. The bony landmark for Ankle Joint was located at fibula head, lateral malleolus and 5th metatarsal; bony landmark for knee joint was placed at lateral malleolus, lateral femoral epicondyle and greater trochanter. The bony landmark for hip joint was located at lateral epicondyle, greater trochanter and medial epicondyle [12].

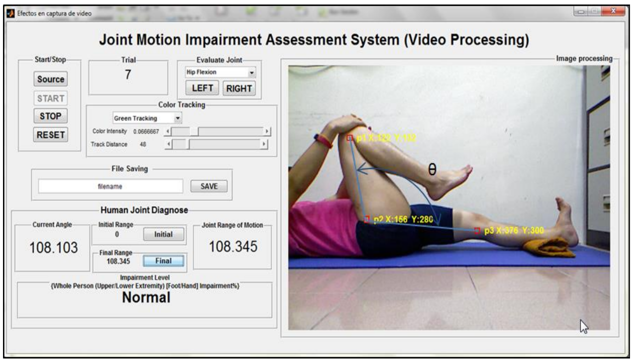


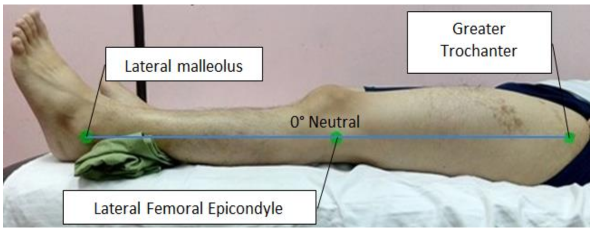
Figure 2: Graphical User Interface of Visual Tracking System for joint motion assessment and displayed the three tracking points on the bony landmark

D. *Electrogoniometer (EGM)*

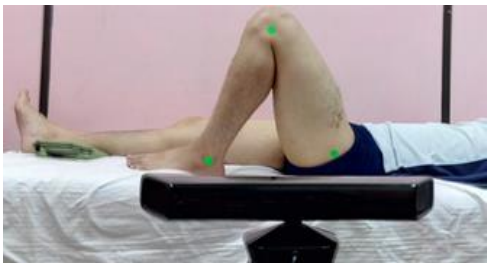
The EGM was attached to the body segment with adhesive tapes. To avoid displacement of the sensors on lower limb joint, they were affixed to the bony landmark. The EGM sensor for ankle was SG110 from Biometrics, Ltd; it was placed parallel to the Achilles tendon. The EGM sensor for the knee and hip was SG150, also from Biometrics, Ltd. The attachment of the EGM endblocks sensor on knee and hip was put at the reference line of lateral malleolus and lateral femoral epicondyle and greater trochanter. For the hip, the EGM sensor was attached proximal endblock to the trunk of pelvis with the reference of greater trochanter (shown in Figure 3).

E. *Universal Goniometer (UGM)*

The lower limb joint flexion range of motion was measured by an adjustable goniometer [13]–[15]. To measure ankle flexion: (1) Axis of goniometer is placed to the lateral malleolus; (2) Stationary arm is parallel to the longitudinal axis of the fibula, lining up with fibula head; (3) Moveable arm needs to be parallel to longitudinal axis of 5th metatarsal. To measure knee movement: (1) Axis of goniometer is placed over lateral femoral midway between maximum anterior to posterior flares of condyle; (2) Stationary arm is parallel to lateral midline of femur (greater trochanter as reference); (3) Moving arm is placed lateral at midline of fibula (lateral malleolus as reference). Placement of universal goniometer on hip flexion: (1) axis of goniometer is placed at lateral hip anterior and superior to trochanter. (2) Stationary arm is parallel to longitudinal axis of the femur line with greater trochanter. (3) Moveable arm is parallel to longitudinal axis of the lateral midline of femur (through Medial Epicondyle as reference). The data for the ankle, knee and hip flexion were recorded for each of the subjects and used to compare with VTS and EGM.



(a)



(b)

(c)

(d)

Figure 3: (a) Bony landmarks for measurement device alignment of knee joint [16] and starting position for measurement of knee flexion (angles are measured as neutral, which is measured as 0°); (b) Location of camera for VTS; (c) Placement of UGM; (d) Placement of EGM

IV. PROCEDURES

The subjects underwent ROM examination of ankle joints, knee joints and hip joints for both left and right sides. The subjects were suggested to stay in the starting position for the certain joint ROM examination. Based on the joint ROM examination, the colour marker was marked on the bony landmark on subject's ankle, knee and hip joints. The EGM sensor of twin axis "SG" and UGM was placed on the subject's joint. For the VTS, the camera was placed facing to subject's joint in parallel at the same height level and around 80 cm in distance. The subjects were then asked to do ROM exercise such knee flexion, hip flexion and ankle plantarflexion. After that the subjects would stay in starting position and do joint flexion at the ending position and repeat the exercise for 5 trials. Then, the data of starting position and ending position were recorded and saved for UGM, EGM and VTS through the experiment session.

A. *Data Analysis*

To identify the system performance, we analyzed the ROM by some parameters which is standard error of measurement (SEM), intraclass correlation (ICC), and Significant Differences (Sign Diff). Accuracy is defined for these investigations as the standard error of measurement [17]. The SEM is calculated from standard deviation as shown in Equation (1):

$$SEM = \frac{SD}{\sqrt{N-1}} \tag{1}$$

The intraclass correlation (ICC) assesses the reliability of ratings by comparing the variability of different ratings of the same subject to the total variation across all ratings and all subjects. The ratings are quantitative. We will assume that the five repeated measurements are taken from a 20 healthy control subjects and use Excel's ANOVA: Two Factor without Replication data analysis. The ICC results are given in Table 1. ICC is considered low if ≤ 0.49, moderate if 0.50 – 0.69, high if 0.70 –0.89, and very high if 0.90 –1.00 [18]. The ICC is then calculated from three types of variability shown in Equation (2):

$$ICC = \frac{var(\beta)}{var(\alpha)+var(\beta)+var(\varepsilon)} \quad (2)$$

where:

var(β) : *(MSRow – MSE)/k* ; variability due to differences in the subjects

var(ε) : *MSE*; variability due to differences in the evaluations of the subjects by the device measurement (e.g. five repeated measurand)

var(α) : *(MSCol – MSE)/n*; variability due to differences in the measurements of trails

n : Number of rows (i.e. healthy control subjects)

k : Number of columns (i.e. measurement = trails)

The significant difference between ROM measurements methods would also be tested for the left and right ankle plantarflexion respectively to determine the validity of the system VTS vs. EGM, VTS vs. UGM, and EGM vs. UGM shown in Table 3, we have to decide between the hypotheses:

H_0 : $\mu_{M1} = \mu_{M2}$, and there is essentially no significant difference between two measurement methods for joint flexion.

H_1 : $\mu_{M1} \neq \mu_{M2}$, and there is a significant difference between two measurement methods for joint flexion.

Using a two-tailed test at 0.05 significant levels, we would reject H0 if t were outside the range -t.975 and t.975. For the degree of freedom is N1 + N2 = 20 + 20 – 2 = 38 the range is -2.0244 to 2.0244.

V. Result And Discussion

The statistical description is done to indicate the statistical values of experiment such as mean, standard deviation, ICC and SEM for the determination of the data quality of three measurement systems during joint motion. The results for the measurement of lower limb joint flexion angle with ICC, SEM, mean and standard deviation values are shown in Table 1. Small SEM values indicate good absolute reliability [19]. ICC for VTS is 0.86 - 0.92, EGM 0.87 - 0.95 and UGM 0.78 - 0.94. Values from the same group tend to be similar and reliability for the VTS, UGM and EGM due to the high ICC. Range of SEM for VTS is 1.12 - 1.98, EGM 1.21 - 6.10; and UGM 1.31 - 1.92. The SEM of VTS is the smallest compare to EGM and UGM. Thus, this SEM shows that the VTS is accurate and good.

Without combining the left and right joint, the comparison is done between the three measurement methods (VTS, EGM and UGM) for the joint motion analysis which have three combinations of VTS vs. EGM, VTS vs. UGM and EGM vs. UGM (shown in Table 2). The H_0 of VTS vs. EGM for left ankle plantarflexion and right ankle plantarflexion are rejected. The H_0 of *VTS vs. UGM* cannot reject produces the highest accuracy for all the joint motions compared to *VTS vs. EGM* and *VTS vs. UGM*. The highest accuracy given 99.46% is provided by *VTS vs. UGM* for left knee flexion. As summary of Table 2, the VTS is able to provide high accuracy of ROM measurement for human lower limb joint as compare to UGM and EGM.

From the Table 3, the significance and hypothesis test for the left and right of the lower limb joint motion provide the same result that H_0 cannot be rejected. It means that the mean and standard deviation of the joint motion are similar for left and right limb. This proves that human left and right limb are similar as shown in previous research [20], [21].

Comparison among the three measurement methods (VTS, UGM and EGM) for the joint motion when left and right limbs data is found by doing analysis on each combination of any two systems as shown in Table 4. The H_0 for VTS_{LR} vs. EGM_{LR} is not rejected and always yields high accuracy compared to another two comparison. This means that both VTS and EGM are produced very different in ROM result. On the other hand, EGM produces bigger error due to the reasons of misallocated of sensors, clothing affect, and drop down of sensor, and difficult to hygienic after being used [22]–[24]. The VTS as well as the UGM is designed based on the goniometry theory. Thus, VTS can provide the accurate ROM better than a UGM because it is a digital device. From Table 4, the knee flexion gives the highest accuracy than other joints because the knee joint can only provide 2 DOF. However, others joint such as ankle joint and hip joint have 6 DOF. Our VTS is providing 2D images data which is more sensitive to 2 DOF. Tables 2, 3, and 4 summarized that VTS is able to produce high accuracy compared to UGM and EGM.

Table 1
Lower Limb Flexion Statistical Analysis, Mean ± Standard Deviation, Standard Error Measurement, Intraclass Correlation and P-Value

Lower Limb Joint Flexion		*VTS*		*EGM*		*UGM*	
		Left	Right	Left	Right	Left	Right
Ankle Plantarflexion	Mean ±SD	37.55 ±6.26	36.87 ±6.29	32.15 ±5.43	32.76 ±5.97	36.15 ±6.40	35.45 ±6.74
	SEM	1.40	1.41	1.21	1.33	1.43	1.51
	ICC	0.86	0.86	0.92	0.93	0.94	0.92
Knee Flexion	Mean ±SD	120.89 ±5.02	119.63 ±5.61	115.05 ±17.33	114.83 ±10.91	120.24 ±5.97	118.34 ±5.85
	SEM	1.12	1.25	3.88	2.44	1.33	1.31
	ICC	0.89	0.86	0.88	0.87	0.78	0.82
Hip Flexion	Mean ±SD	114.35 ±8.84	114.98 ±7.99	101.36 ±27.26	103.83 ±24.32	113.24 ±8.60	113.82 ±7.44
	SEM	1.98	1.79	6.10	5.44	1.92	1.66
	ICC	0.91	0.92	0.95	0.87	0.89	0.79

Table 2
Comparison among the Three Measurement Methods for Joint Motion without Combining Left and Right Limbs Data for Analysis

Lower Limb Joint Motion		*VTS vs. EGM* Left	*VTS vs. EGM* Right	*VTS vs. UGM* Left	*VTS vs. UGM* Right	*EGM vs. UGM* Left	*EGM vs. UGM* Right
Ankle Plantarflexion	Sign. Diff.	Reject H0	Reject H0	Cannot Reject H0	Cannot Reject H0	Reject H0	Cannot Reject H0
	Accuracy	83.19%	87.44%	96.12%	96.00%	88.93%	92.40%
Knee Flexion	Sign. Diff.	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0
	Accuracy	94.92%	95.82%	99.46%	98.90%	95.69%	97.04%
Hip Flexion	Sign. Diff.	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0	Cannot Reject H0
	Accuracy	87.18%	89.26%	99.02%	98.98%	89.51%	91.22%

Table 3
Significant Differences between Left and Right Limb Joint Motion

Joint Motion		VTS_{LR}	EGM_{LR}	UGM_{LR}
Ankle Plantarflexion	Sign. Diff.	Cannot Reject H_0	Cannot Reject H_0	Cannot Reject H_0
	Accuracy	98.15	98.15	98.03
Knee Flexion	Sign. Diff.	Cannot Reject H_0	Cannot Reject H_0	Cannot Reject H_0
	Accuracy	98.95	99.80	98.39
Hip Flexion	Sign. Diff.	Cannot Reject H_0	Cannot Reject H_0	Cannot Reject H_0
	Accuracy	99.45	97.62	99.49

Table 4
Significant Differences among Two Measurement Methods for Limb Joint Motion

Joint Motion		VTS_{LR} vs. EGM_{LR}	VTS_{LR} vs. UGM_{LR}	EGM_{LR} vs. UGM_{LR}
Ankle Plantarflexion	Sign. Diff.	Reject H_0	Cannot Reject H_0	Reject H_0
	Accuracy	85.34%	96.06%	90.65%
Knee Flexion	Sign. Diff.	Reject H_0	Cannot Reject H_0	Cannot Reject H_0
	Accuracy	95.37%	99.18%	96.36%
Hip Flexion	Sign. Diff.	Reject H_0	Cannot Reject H_0	Reject H_0
	Accuracy	88.23%	99.00%	90.37%

VI. CONCLUSION

From the SEM we found that VTS have the smallest SEM with averaged of 1.49 compared to EGM 3.4 and UGM 1.53. Thus, VTS give the high accurate in averaged lower limb measurement. From significant differences between left and right limb joint motion it was found that left and right limb joint are similar for Ankle plantarflexion, Knee Flexion, and Hip Flexion of the healthy subject. Thus, our VTS able to identify the lower limb injured subject by analyzing the similarity of left and right limbs flexion. When the comparison is done between two systems among the three measurement methods for joint motion without combining left and right limbs data for analysis, we found that EGM had the big significance difference with VTS and UGM. This situation happens due to the EGM limitations which are sensor misallocation; drop down of sensor and so on. The performance of VTS and UGM are relatively the same when the result of UGM is provided by the experienced user. However, the result will be influenced when the UGM is used by a learner.

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