

Measuring Ankle Angle and Analysis of Walking Gait using Kinovea

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ABSTRACT

Understanding the biomechanics of motion related to human walking gait is important in the area of rehabilitation. Infrared cameras motion capture systems have been widely used. Nevertheless, the system is very expensive and thus alternative solutions are explored. This study is aimed to measure the angle of ankle during walking and then assess the reliability of Kinovea in analysing walking gait. Firstly, a motion capture-analysis system combining HD VideoCam-Kinovea was validated. Then, a motion capture-analysis system combining HD DSLR Camera-Kinovea was used to capture the motion of walking and the relative angles of ankle during walking gait phases are measured. Three volunteered healthy subjects without any gait disorders, age ranged from 20 - 24 years were recruited for this study. Basic statistical analysis was carried out to compute the mean, standard deviation (SD) and variance. In terms of walking gait analysis that is the main part of the current study, the results revealed no statistically significant difference (variance < 5%) in the measured data for the same subject under five trials. This proves that the protocol is repeatable and the current system combining HD DSLR Camera-Kinovea is reliable.

INTRODUCTION

The study of the motion of living things applying the science of mechanics is also known as biomechanics (Knudson, 2004). Motion analysis of human gait is a famous branch of biomechanics, where the studies has started since the late 1900s (Soutas-little, 1998; Kadaba et al., 1989; Baker, 2006; Johanson et al., 2006; Moriguchi et al., 2007). Therefore, this proves that understanding the biomechanics of motion related to human walking gait is important (Palmer, 2002; Umberger, 2010), especially in rehabilitation (Brockett, 2016; Muro-de-la-herran, 2014). Due to that, valid and reliable assessment tools are necessary (Elwardany et al., 2015). Infrared cameras motion capture systems have been widely used, where generally these are the established systems. Nevertheless, these systems are relatively very much expensive and thus alternative solutions have been explored (Damsted, 2015). Microsoft Kinect is one of the potential tools to be further developed as a motion capture tool due to its low cost, portability and ease of use (Bonnechere et al., 2014; Bujang et al., 2015). Many types of research have been conducted to explore Kinect for motion capture-analysis purposes (Mustapha et al., 2016; Raposo et al., 2013, Yusuff et al. 2015). Nevertheless, Kinect is the motion capture system but for motion analysis, a programme of software is needed.

Kinovea is an open-access video analysis software and available online (<https://www.kinovea.org>), which could be explored for motion analysis (Guzmán et al., 2013; Elwardany et al., 2015). Despite it is increasingly popular to be used for video analysis related to sports performance, its accuracy and repeatability as a motion analysis tool in gait analysis have not been well address.

Therefore, this study aims to measure the angle of ankle during walking and then assess the reliability of the Kinovea in analysing walking gait. This is novel as no similar work employing HD Camera-Kinovea used for analysing walking gait and assessing its repeatability, has been reported before.

MATERIALS AND METHOD

System Validation

Initially, to assess the reliability of the Kinovea in tracking and analysing, a motion capture-analysis system using of a Sony HD VideoCam-Kinovea has been developed and tested. Performed at the Biomechanics Lab, Shibaura Institute of Technology, Omiya Campus, Japan, a volunteered healthy volunteer without any gait disorder was asked to walk on a preset platform. For validation purposes, the walking gait was simulatenously recorded using an established infrared motion capture system (Hawk-Cortex, M.A. Corporation, 2015) and a Sony HD VideoCam. The outputs (video recordings) from the HD VideoCam were input into Kinovea (an open-source software) and the walking gait pattern was tracked and analysed. These data are compared with the walking gait pattern tracked and analysed earlier using the Hawk-Cortex system. Using basic statistical analysis, the value of mean, standard deviation and variance were computed and the results obtained (walking gait pattern) using the HD VideoCam-Kinovea are close to the results obtained using the established motion capture system. The system setup, protocol and results have been presented in details by Hisham et. al. (2017).

Parameters and Experimental Setup

Prior to coming up with the optimum set up and field of view, the camera system (Digital Camera, CANON EOS 600D) was explored thoroughly. Important parameters such as Subjects Area, Camera Position, Camera Focal Length and Aperture, Focus Point, Motion Speed, Capturing Speed have been tested to obtain the best possible video quality and optimum field of view. Finally, the optimum camera position and angle was found, where the camera was placed on a level tripod, perpendicular to the centre of the pathway at a distance of 2.43m (8ft) and approximately 0.3048m (1ft) above the floor for the preset field of view (Fig. 1). This calibrated field of view covered

clearly the subjects' the lower limb during motion. The optimum camera lens focus point and aperture were also preset to produce clear and sharp 2D images and videos. The location chosen was the UiTM Stadium where the camera was placed and the subjects walked on the track to ensure the good quality, level, aligned walking path. Signs and markings are put on important locations, such as the camera position, walking start point, centre point, etc. This is to ensure that all the positions are the same for all subjects at any time and day of capture. In general, for one subject, the complete experiment including marker placement, took total of about 20 minutes.

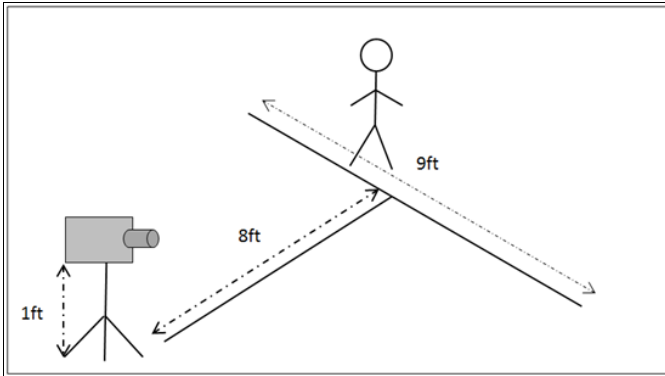


Fig. 1: Illustration of the calibrated plane, camera position and field of view.

Experimental Protocols

A total of three volunteered healthy subjects without any gait disorders, age ranged from 20 - 24 years (mean BMI of 28.60 ± 1.40) were recruited for this study. Each subject was given a full explanation, verbal instruction concerning the purpose and procedure of the study. Informed consent was obtained from all the volunteered subjects with ethical approval from Universiti Teknologi MARA Research Ethics Committee, under the part of the study related to the development of motion capture-analysis system. Upon agreed, markers were placed on the lower limb at a specific location as shown in Fig. 3. It is important to note that even though the system used (DSLR Camera- Kinovea) is considered as markerless motion capture system, the markers provide a good focal point during motion tracking (video playback) using Kinovea. Each subject was asked to walk at normal pace on the preset track (Fig. 4). For each subject, the walking protocol was repeated for five times and the motion (focusing on the walking gait) was video recorded using a DSLR Camera, CANON EOS 600D.



Fig. 2: The markers' position on a subject.



Fig. 3: Heel strike position captured by the HD digital camera and displayed in Kinovea.

Motion Tracking Using Kinovea

Kinovea was used to retrieve all of the outputs (images and videos) from the DSLR camera. All of the recorded video (video files) was first playback to check for any obvious error. Low quality captures were also discarded. For the accepted videos, Kinovea was used to locate and specify all the five main markers (Fig. 2), which the process was very similar for tracking markers using the infrared motion capture system. Kinovea kept track of the marker movement for the whole capture (walking gait). The example procedure for tracking and the example output at heel strike is shown in Fig. 3.

Angle Measurement

Fig. 3 shows a sample instance (image) from a complete cycle of a walking gait. Using Kinovea, three points (markers) were selected in order to measure the relative angle of the ankle for any instance. The main marker under consideration was the ankle. The other two markers include the two markers adjacent to the ankle. From these 3 points (markers), the relative angles of ankle were determined. During walking gait, the relative angles of ankle change with respect to the motion. Instead of time, the important parameters determined in this study are angle changes with respect gait cycle. The data is stored according to subject and trials. Since 3 subjects performed 5 trials, in general, 15 videos have been analysed and the data is stored for Repeatability Analysis

Repeatability Analysis

To measure the repeatability of the system, the data for all subjects and trials (total of 15 videos) were analysed. Basic statistical analysis was carried out to compute the mean, standard deviation (SD) and variance using Eq. (1) to Eq. (3) (Interval, 2003; CollegeBoard, 2015). Even though the data is complete for the full walking gait cycle, for this study the data is analysed only on the 8 gait phases (Hisham et. al., 2017; Kharb et al., 2011), which are during Heel Strike (start of cycle), Footflat, Midstance, Heel Rise, Toe off, Initial swing, Mid swing and Terminal swing (end of cycle).

$$\bullet \quad \text{Mean } (\bar{x}) = \frac{\sum x}{n} \quad (1)$$

$$\bullet \quad \text{Standard deviation (SD)} = \sqrt{\frac{\sum (x - \bar{x})^2}{n}} \quad (2)$$

$$\bullet \quad \text{Variance} = \frac{\sum (x - \bar{x})^2}{n} \quad (3)$$

RESULTS AND DISCUSSION

The results and discussion to validate the current system compared to Hawk-Cortex system, has been presented in detail by Hisham et. al., (2017), prior to this paper. In general the results prove

that show that the current system has been validated, thus conforming its accuracy. The main objective of this paper is to measure the angle of the ankle during walking and then assess the reliability of Kinovea in analysing walking gait. Therefore, the results and discussion of the current study focuses on these objectives, which are related to ankle angle measurement using Kinovea and the reliability of the current system in analysing walking gait.

In general, the tracked relative angles of ankle and statistical data for all subjects and trials have been obtained. These data are plotted into graphs showing the walking gait for each subject and trials. The data (Table 1) and graph (Fig. 4) for Subject 1 are presented as an example of outputs in Table 1 and Fig. 4. Table 1 shows the Relative Ankle Angle for Walking Gait Phases for Subject 1. The data originally is obtained from the graphs in Fig. 4 that depicts the Measured Relative Ankle Angle ($^{\circ}$) of walking gait cycle for the same subject. It shows the walking gait for all the five trials captured using the DSLR camera and tracked using Kinovea. The mean curve is highlighted. Except during Foot flat, in general, the data reliable since the protocol is considered repeatable when variance $< 5\%$ as in Table 1 (Mahmud et al, 2010). Therefore, the results revealed no statistically significant difference in repeatability of the measured data. The biggest variance is found in Trial 1. The trend is clearly observed in Fig. 4, where in general the all the curves are close to each other.

Table 1: Relative Ankle Angle for Walking Gait Phases (Subject 1).

SUBJECT 1	HEEL STRIKE	FOOT FLAT	MID STANCE	HEEL RISE	TOE OFF	INITIAL SWING	MID SWING	TERMINAL SWING
1	88	111	96	85	113	104	85	85
2	83	106	97	88	110	99	82	85
3	86	105	96	87	111	101	80	85
4	83	101	96	90	111	102	80	88
5	82	102	95	88	115	101	80	84
AVG	84.4	105	96	87.6	112	101.4	81.4	85.4
S.D	2.24	3.52	0.63	1.62	1.79	1.62	1.96	1.36
VARIANCE	5.04	12.4	0.4	2.64	3.2	2.64	3.84	1.84

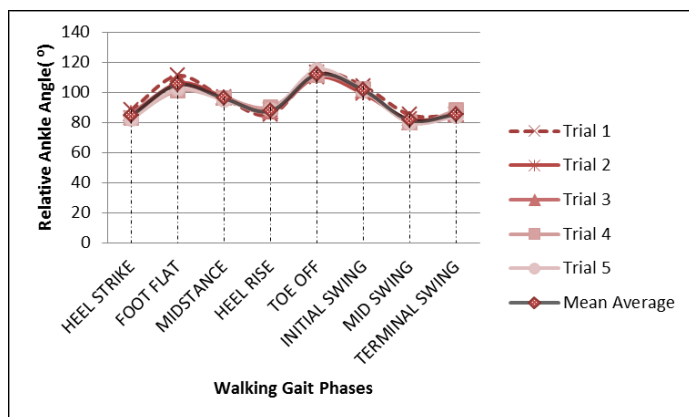


Fig. 4: Measured Relative Ankle Angle ($^{\circ}$) of walking gait cycle (Subject 1).

Fig. 5 shows the mean curves for the Relative Ankle Angle ($^{\circ}$) of walking gait cycle for all subjects. Generally, all the graphs exhibit relatively the similar curve. This is true as all subjects are healthy and normal, thus should exhibit a normal gait. The differences in peak values at each phase were due to the variability of subjects as different subjects possessed their own walking gait cycle.

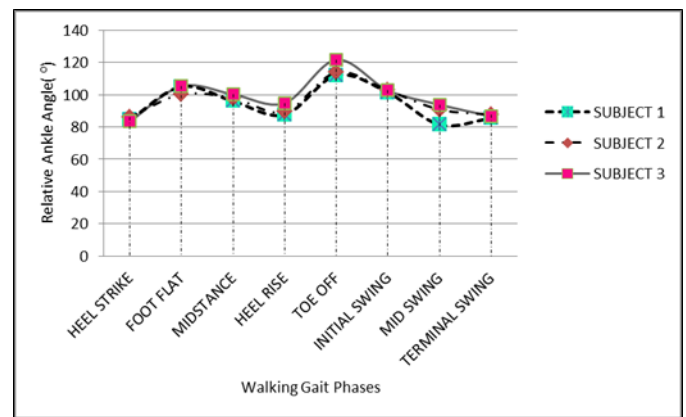


Fig. 5: Graph of Relative Ankle Angle ($^{\circ}$) at each walking gait phases of every subject.

CONCLUSION

This paper has presented the measuring of ankle angle during walking and the assessment of reliability in analysing walking gait using Kinovea. Prior to this paper, earlier results presented by Hisham et. al., (2017) show that the current system has been validated when compared to Hawk-Cortex system, thus conforming its accuracy.

In terms of walking gait analysis, the main results and finding of the current study reveal that there is no statistical significant difference (variance $< 5\%$) in the measured data for the same subject under five trials. Therefore, this proves that the protocol is repeatable and the current system combining HD DSLR Camera-Kinovea is reliable.

When comparing the walking gait for all three subjects, the curves in general exhibit a relatively similar walking gait. By testing on many more subjects, the walking gait cycle for normal and healthy subjects could be established. The current study will also be expanded to cover other applications such as sports biomechanics and rehabilitation, other range of motions and test on many more subjects. In addition, a more comprehensive analysis will be conducted to further assess the accuracy and reliability of Kinovea in order to explore its full potential. As a conclusion, this study and paper have contributed significant and new knowledge about walking gait analysis using HD DSLR Camera-Kinovea system.

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Informed consent was obtained from all the volunteered subjects with ethical approval from Universiti Teknologi MARA Research Ethics Committee, under the part of study related to the development of motion capture-analysis system using Kinect and Matlab (REC/187/16) and 600-RMI/FRGS 5/3 (76/2013)).

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REFERENCES

Baker, R., 2006. Gait analysis methods in rehabilitation. , J Neuroengineering Rehabil., vol. 10, pp. 1–10.

- Bonnechere, B., Jansen, B., Salvia, P., Bouzahouene, H., Omelina, L., Moiseev, F. and Jan, S. V. S. 2014. Validity and reliability of the Kinect within functional assessment activities: comparison with standard stereo photogrammetry. *Gait & Posture*. vol. 39, no. 1, pp. 593-598.
- Brockett, C.L., 2016. Biomechanics of the ankle. *Orthopaedics and Trauma*, vol. 30, no. 3, pp.232-238.
- Bujang, K., Nazri, A.F.A., Azam, A.F.A. and Mahmud, J. 2015. Development of a Motion Capture System Using Kinect, *Jurnal Teknologi*, vol. 76, no. 11, pp 75-86.
- CollegeBoard New York. 2015. Quantitative Skills and Analysis in AP ® Physics 1 and 2 Investigations: A Guide for Teachers.
- Damsted, C., Nielsen, R.O. & Larsen, L.H., 2015. Reliability of Video-Based Quantification of The Knee and Hip Angle at Foot Strike During Running., *Int J Sports Phys Ther.*, vol. 10, no. 2, pp. 147-154.
- Elwardany, S.H., El-Sayed, W.H. & Ali, M.F., 2015. Reliability of Kinovea Computer Program in Measuring Cervical Range of Motion in Sagittal Plane. *Open Access Library Journal*, vol. 2, pp.1-10.
- Guzmán-Valdivia, C.H., Blanco-Ortega, A., Oliver-Salazar, M.A.y Carrera-Escobedo, J.L., 2013. Therapeutic Motion Analysis of Lower Limbs Using Kinovea. *International Journal of Computing and Engineering*, vol. 3, no. 2, pp.359-365.
- Hisham, N.A.H., Samsudin A.H., Mahmud, J., Komeda, T., Patar, M.N.A.A., Yamamoto, S-I., 2017. Walking Gait Analysis Using Kinovea And Motion Capture System: A Comparison, in the proceedings of IEEE 6th International Conference on Electrical Engineering and Informatics 2017 (accepted).
- Interval, M., 2003. Variance and standard deviation (grouped data).
- Johanson, M.A. et al., 2006. Heel Lifts and the Stance Phase of Gait in Subjects with Limited Ankle Dorsiflexion", *Journal of Athletic Training*, 41(2), pp.159-165.
- Kadaba, M. P., Ramakrishnan, H. K., Wootten, M. E., Gaine, J., Gorton, G., and Cochran, G. V. B. 1989. Repeatability of Kinematic, Kinetic and Electromyographic Data in Normal Adult Gait. *J Orthop Res.*, vol. 7, no. 6, pp. 849-860.
- Kharb, A., Saini, V., Jain, Y.K., Dhiman, S., 2011. A review of gait cycle and its parameters, *International Journal of Computational Engineering & Management*, vol. 13, pp. 78-83.
- Knudson, D., 2004. *Fundamentals of Biomechanics*, 2nd edition, Springer .
- M. A. Corporation, "Cortex 6.0 Reference Manual," 2015
- Mahmud, J, Holt, C.A. and Evans, S.L. 2010. An innovative application of a small-scale motion analysis technique to quantify human skin deformation in vivo, *Journal of Biomechanics*, vol. 43, no. 5, pp 1002-1006, 2010.
- Moriguchi, C.S., Sato To E. Gil H.J.C. Coury, 2007. Ankle Movements During Normal Gait Evaluated by Flexible Electrogoniometer, *Rev. bras. fisioter.*, São Carlos, vol. 11, no. 3, pp. 205-211.
- Muro-de-la-herran, A., Garcia-zapirain, B. & Mendez-zorrilla, A., 2014. Gait Analysis Methods: An Overview of Wearable and Non-Wearable Systems, Highlighting Clinical Applications. *Sensors*, vol. 14, no. 2, pp.3362-3394.
- Mustapha, G., Razak, M.F.A., Hamzah, M.S.M., Yahya, N.H.M. and Mahmud, J. 2016. The Development of a Low Cost Motion Analysis System: Cekak Visual 3d V1.0. *International Journal of GEOMATE*, Vol. 11, No. 24, pp. 2248-2252.
- Palmer, M.L., 2002. Sagittal Plane Characterization of Normal Human Ankle Function Across a Range of Walking Gait Speeds.
- Raposo, C., Barreto, J. P. and Nunes, U. 2013. Fast and accurate calibration of a kinect sensor. *3D Vision-3DV 2013*, 2013 International Conference. pp. 342-349.
- Soutas-little, R.W. & Ph, D., 1998. Motion Analysis and Biomechanics, *J Rehabil, Res Dev, Monograph 002*, pp. 49-68,.
- Umberger, B.R., 2010. Stance and swing phase costs in human walking. *J. R. Soc. Interface*, vol. 7, pp. 1329-1340.
- Yusuff, K.M.S.T., Nazri, A.F.A., Mustapha, G, and Mahmud, J. 2015. Analysis of Static and Dynamic Motion Accuracy for Kinect-virtual Sensei System, *ARPN Journal of Engineering And Applied Sciences*, vol . 10, no. 17, pp 7328-7335.