RESEARCH ARTICLE

A Footprint Analysis: Comparison between Conventional Scanning Method and Motion Capture System

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Abstract Footprint is a key element in human physiological characteristic study, for determining gender, height and weight. This study is to investigate the reliability of using conventional scanning method by comparing results with motion capture system method. The study takes footprint images from conventional scanning and processed using MATLAB. The captured gait movement data are generated from Vicon Nexus and Vicon Polygon respectively. Afterwards the data from the two methods were analysed for correlation test. The significant difference between measurement of gait parameters using Vicon and conventional scanned method were tested using paired sample t-test and the concurrent validity of conventional scanned method was tested using Pearson correlation. Although there was significance difference between measurement using both methods, the correlation analysis displayed moderate to high positive significant correlation of the parameters indicating the validity of the conventional scanned method.   This concludes this study to accept the alternative hypothesis that there is a linear relationship between these two procedures.

Keywords: Footprint, scanning method, motion capture system.

Introduction

Footprint is a mark left by a person standing, walking or running. Footprint analysis is essential for a person to wear a suitable foot-wear design, fit evaluation and clinical applications [1] such as rehabilitation purposes, foot anthropometric check-ups and body posture related test [2]. Footprint is commonly found as authentic evidence during crime investigation similar to fingerprints on victim or surrounding things. As every human possesses different and unique way of walking, forensics have been applying foot and gait analysis in identifying people to solve crime [2].

Often footprint can be seen on beaches, muddy ground during rainy days and fresh wet cement. Forensic science makes use of footprint as a determinant for specific characteristics of humans like height, weight, age and gender. Features of the humps, phalange marks, crease marks and flatfoot condition are few of criteria studied and appeared to be distinct for people live in different regions, come from different races and from opposite gender [3]. The size of footprints even varies for when people are walking and running, and standing still [4]. Besides the stains on feet, the body weight and height could be playing some roles in the size of footprint.

Gait defines the body movement characteristics of walking or running, and a methodical study of human locomotion is called as gait analysis. It aimed at implementation in clinical practice seeks to explain in details the mechanical and motor impairments of the lower limbs in general and their implications for locomotive disability with the focus on ambulation [5]. Instrumented 3D-gait analysis is used to obtain information that is critical in assessing the degree of pathology-related functional impairment, studying its progression over time, and evaluating rehabilitative results [6].

Numerous numbers of method have been used to study the human footprint for various reasons namely the walking pattern, lower limb condition and to identify human characteristics. Motion capture system is the best suggested method to study gait pattern as it captures the most accurate movement of human body. However, the rarity used of 2D scanning method in previous studies lead to the study of comparison between both modalities. Thus, the relevance of scanning method can be figured.

Every person should have access to get the research done in the most economical way they could afford. A scanning method could be an addition to the other options they already considered. The similarity of results between these two approaches can be observed through the parameters. Thus, comparing them and finding their correlation could be the solution. The objectives include to identify walking parameter derived from 2-dimensional (2D) scanned footprint and motion capture system, to perform data collection of footprints for image processing and motion analysis and to analyze data by using comparative study and correlation study. It is assumed that there is no linear relationship between conventional scanning method and motion capture system (H_o).

Literature Review

With updated technology, portable 3D laser scanner has been developed making the documentation of footprint on site to be easier. Regular used of 3D laser scanner is on crime scene to capture unknown marks on hidden graves, footprints, fingerprint and teeth marks in soft and decayed food, burned remains in fire scenes or dental details to be analysed during post-mortem [7]. The growth of children feet between the ages of two, five and seven are observed from 3D shape descriptors derived from 3D scanning data [8] proved that with the increase number of ages, the changes in distribution curvedness of data in the medial, dorsal and lateral surfaces implied that the whole shape of foot become less rounded with age. 3D scanning is comparably a reliable medium to measure not only foot morphological but also footprint and other dubious marks large or small.

Another study [9] used HP Scanjet G2410 that features high resolution flatbed photographic scanner. It managed to produce clear edges of footprint image that ease the process of extracting the outlines of footprints. The authors used MATLAB functions to acquire database, to enhance and extract the feature of footprint images and to calculate the output measurements through the stages of image processing framework which are preprocessing of image and filtering [9].

Motion capture system

As motion capture systems commonly used on athletes, a few motion capture systems used in sports applications includes Electromagnetic Measurement Systems (EMS), Image Processing Systems (IMS), Optoelectronic Measurement Systems (OMS) and Inertial Measurement Unit (IMU) [10]. The efficiency

of the systems makes them highly an option for kinematics measurements [10]. It is normal for the trajectories of closely spaced markers to cross each other in video motion analysis systems, making it extremely difficult for the system to monitor automatically, therefore, in the current system, only two markers were used on the foot to describe the restriction of ankle joint movement to flexion-extension and internal-external rotation [11]. The validity of Microsoft Kinect and Vicon system towards sagittal plane hip and knee kinematics were evaluated at different velocities [12]. The authors found that the accuracy of Kinect measurements is not acceptable to analyze clinical measurements due to inconsistent hip measurements, inability to measure the total extent of hip and knee maximum flexion and limitation in angle used to track movement of hip and knee. Thus, indicating that Vicon system is a more reliable approach to be used [12].

The accuracy and precision of motion capture system has been assessed by controlling some of parameters which are three different laboratories used, the marker size and marker speed in the given workspace [13]. The authors used different types of motion analysis namely Vicon motion analysis system and low-cost motion analysis system design for kinematic gait analysis for neurological service patient in the hospital. They found that Vicon system showed steady and similar trends of mean absolute inter-marker distance error for marker size and speed while able to logically monitor minor changes in the measuring device elements and providing accurate results [13]. In contrast, the low cost motion analysis system is not able to show specific patterns that can show connections with theoretical concepts on independent parameter which are the marker size and the speed towards the accuracy of motion capture systems [13]. Thus, making this device only suitable to be used on big ranges movement like gait studies.

Limitation

Although 3D scanning may has offer the best way to capture footprint, it needs a power source to operate unless the user opt for a battery-operated 3D scanner [7]. If a study was done in a remote area, a place where there is a scarce for electricity, other technique should be considered. The budget planned for a study or investigation must be aligned with the total amount needed to afford a 3D scanner and people who are on a tight budget need to think of a substitute for this 3D scanner or pick a more affordable scanner [7]. Generally, a user should be equipped with skills in using 3D scanner as for some scenes could be complex that it should be scanned multiple times to cover all angles and if the scene has become too complicated, the scanned images could be having artifacts on the images that can be misinterpreted [14].

A test was conducted [15] to observe the result of the length of foot during gait using motion analysis. It also figured that as the subjects started walking, there were displacement of markers on foot due to skin movements that could affect the results. The size of plantar of foot was different when the subjects lift their foot and when they landed it on a surface. The speed of walking has given minimal effect on most parameters. Nevertheless, it was still one thing to be aware of to make sure the measurements acquired are accurate and precise [15].
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Methods

Four women subjects were recruited according to these characteristics :
- Age   : 23 years old (mean age)
- Weight   : 48.98 kg (mean weight)
- Height   : 151.25 cm (mean height)
- BMI (normal)   : 21.45 (mean BMI)

Anthropometric data measurements of lower limbs measurement that includes leg length, knee width and ankle width were taken before starting the experiment and served as a fundamental information when conducting subject's walking experiment. Black ink was used as medium to stamp footprint on A1 paper for manual measurements and to be calculated by MATLAB. The subject was asked to perform preliminary walking trial for the purpose of making the subject felt familiar to the walkway and to have a normal walking pattern. The subject was then standing ready at initial point of two meters walkway. The data were taken at the same time as those methods were being conducted simultaneously.

The subjects stained their feet in black ink and carefully walked on the walkway from the initial point. As the walking has reached the end point, black footprints were spotted on A1 paper and dynamic gait data were recorded and saved using Vicon Nexus. Scanned images of footprints were processed via MATLAB while Vicon Nexus was used for motion capture system with the help of Vicon Polygon for reporting. Comparison between the results were done using correlation study of statistical t-test. Documentation

was done throughout the project to record the progress and findings made.

Figure 1 showed the walking experiment setup in the lab. From the figure, it can be seen that the distance from the starting point to the end point is 2m. A tray of ink has been put on top of the square mark called small box right after static gait data been captured for conventional method. Eight Vicon cameras has been set up in the laboratory. Two pieces of A1 paper were used to collect the stamped footprints and Vicon Nexus in the computer was used.
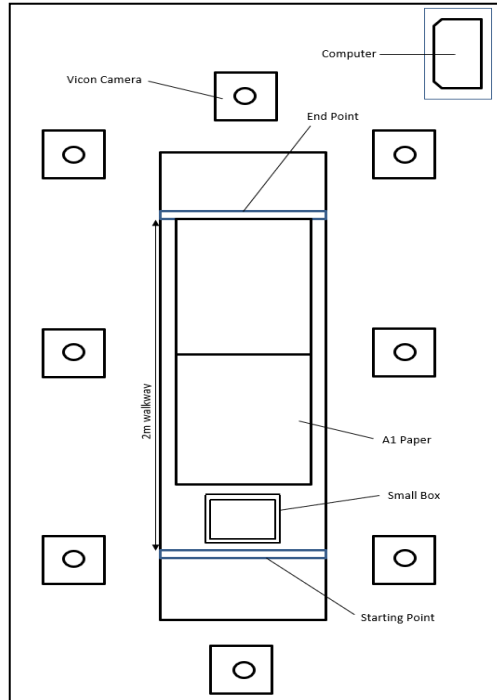

Figure 1. Walking experiment setup in the lab

MATLAB

Footprints from the walking experiment were scanned and MATLAB was used as a medium to do image processing on the images of footprints. Lines were drawn on the images for the purpose of getting the most accurate length of spatial measurements in Figure 2. The stride length and step length for one cycle of walking was shown in the figure below. The MATLAB programming code was applied to acquire the output. The formula used for step length and stride length [16], and walking speed [17] were based on previous studies.
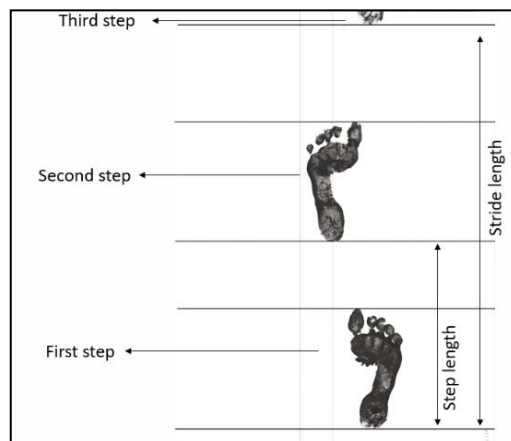

Figure 2. Footprints of subject

Precautions

Some precautionary steps include 14mm marker used was suitable for body parts. The experiment was repeated as every subject has to do three trials of walking experiment to get an average of data. Sufficient cameras were used to record the movement of subjects at every angle. Subjects needed to wear fit attire to prevent any covered marker by the clothes during walking. The subject has to be careful to start walking after staining their feet with black ink as it was slippery.

Statistical analysis

All statistical analysis was carried out in SPSS (SPSS v27, IBM Corp, USA). All features were tested its normality using the Shapiro–Wilk test with a p-value ≤0.05. As all the parameters were normally distributed, paired sample t-test was conducted to test the difference ($p < 0.05$) between the gait parameters collected from the Vicon and the conventional scanned method and processed from MATLAB. Finally, Pearson correlation ($p < 0.05$ [2-tailed]) was used to assess the validity of the conventional scanned method.

Results and discussion

Footprint analysis is mostly important in the forensic gait pattern investigation. It can link or unlink a suspect to a crime scene during the investigation. Other than that, human movement in sports and healthcare can be monitored for their optimal performance in sports and clinical characteristics respectively.

In this study, three trials of data from 4 subjects were taken for both left and right foot. Paired *t*-test was applied to compare the gait variables between the legs.

The graphs in in Figure 3, Figure 4 and Figure 5 illustrated the mean of parameters by the subjects. Generally, Vicon generated lower distance and speed compared to MATLAB. Subject 3 and subject 4 has the same distance of 1.23 m stride length for left foot calculated by MATLAB. The lowest distance of step length can be observed at the right foot of subject 2 for Vicon data (d = 0.38 m) while MATLAB generated the highest result for the right foot of subject 1 (d = 0.81 m). The highest speed (d = 2.00 m) was shown by subject 1 on the right foot while the lowest speed (d = 0.39 m) can be seen at subject 4's right foot. Both were calculated by Vicon.
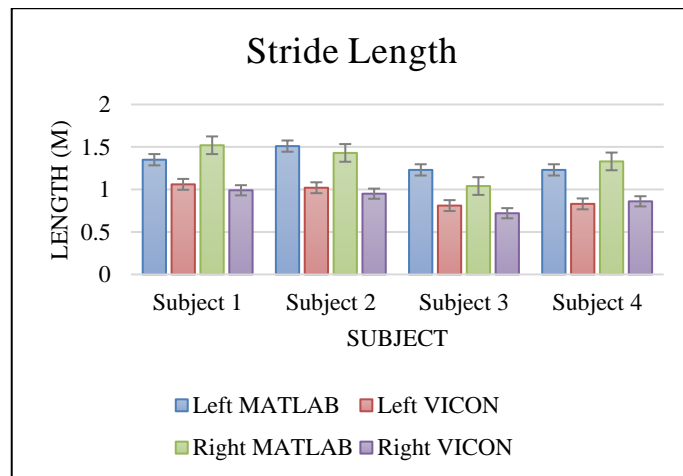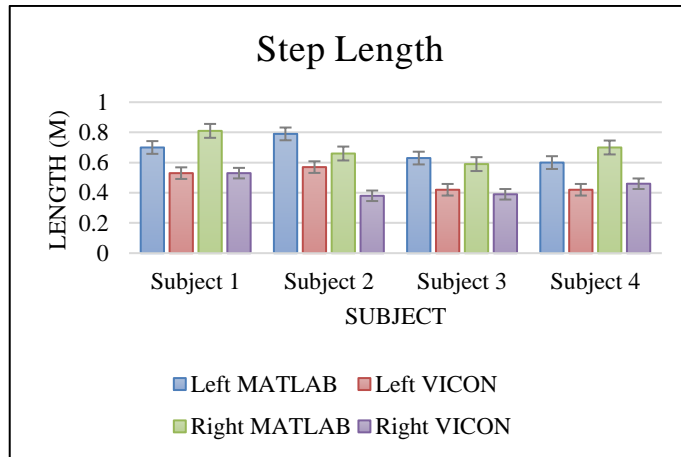

Figure 3. Stride length
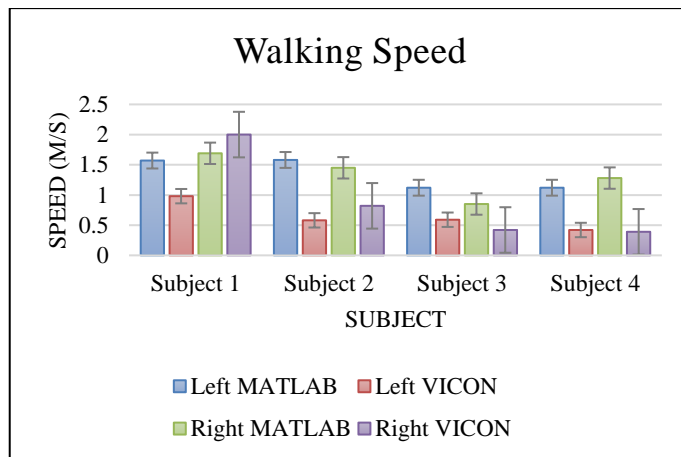
Figure 4. Step length

Figure 5. Walking speed

T-test

The analysis of data to see the correlation between these two methods and the hypotheses were as follows :

- $\alpha : 0.05$
- $H_o : \rho = 0$
- $H_1 : \rho < 0.05$

The following results have been tabulated in Table 1 and Table 2. The graph of Pearson correlation was plotted in Figure 6. Mean values for each gait parameter were indicated in Tables 1 and 2.

The data collected from MATLAB analysis in average shows higher results as compared to the Vicon for all stride length, step length and walking speed for both left and right foots. The reason could be due to the images displayed were too big in MATLAB since they were scanned manually for MATLAB analysis. Besides, the ink used as a medium to get footprints caused smudges and blurred the footprint edges. This made the measurement of footprint to be slightly different from actual value. In this case it gave slightly higher values as compared to the Vicon data.

**Table 1.** Statistical data from t-test for the left side.

Gait parameters	Vicon (Mean ± SD)	MATLAB (Mean ± SD)	p-value of paired sample t-test	Pearson correlation coefficient, r	p-value
Stride length (m)	0.931 ± 0.153	1.328 ± 0.269	0.000	.743*	0.006
Step length (m)	0.483 ± 0.096	0.680 ± 0.118	0.000	.609*	0.036
Walking speed (m/s)	0.643 ± 0.240	1.598 ± 0.399	0.000	.680*	0.015

*. Correlation is significant at the 0.05 level (2-tailed).

Table 2. Statistical data from t-test for the right side.

Gait parameters	Vicon (Mean ± SD)	MATLAB (Mean ± SD)	p-value of paired sample t-test	Pearson correlation coefficient, r	p-value
Stride length (m)	0.881 ± 0.132	1.328 ± 0.211	0.000	.946*	0.000
Step length (m)	0.442 ± 0.076	0.691 ± 0.117	0.000	.909*	0.000
Walking speed (m/s)	0.574 ± 0.218	1.508 ± 0.393	0.000	.677*	0.016

*. Correlation is significant at the 0.05 level (2-tailed).
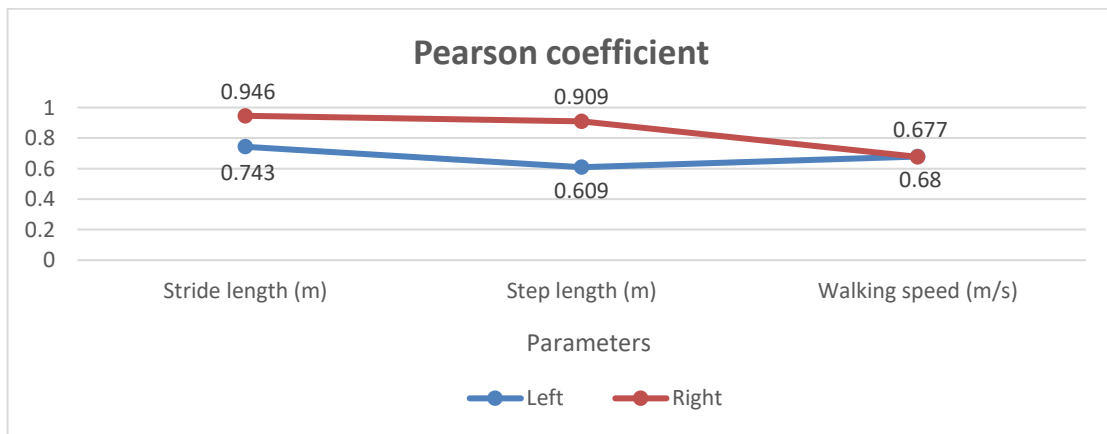
Figure 6. Pearson correlation

Stride length

For stride length on the left foot, the $p < 0.05$ was statistically significant. It has a very strong positive relationship as the $r(2) = 0.743$. Thus, it has a strong positive relationship between MATLAB and Vicon. The stride length of the right foot has a $p < 0.05$. It crossed off the null hypothesis and have a significant p-value. The $r(2) = 0.946$ was very close to 1 and in fact, it was the closest value compared to all other Pearson coefficient values. MATLAB and Vicon results for stride length of the right foot has a very strong positive relationship.

Step length

For step length, p < 0.05 for left foot and p = 0.001 for right foot. Both values were less than the alpha value indicating that they were significant. From the graph above, step length illustrated slightly higher value for the left foot than the right foot. With both having Pearson coefficient close to 1 (r(2) = 0.96 on the left and r(2) = 0.92 on the right), they showed that there were a very strong positive relationship between MATLAB and Vicon for step length.

Walking speed

The results of p = 0.015 for the left foot and p = 0.016 for the right foot, both displayed values less than alpha proving that they were significant. Pearson coefficient of both left and right foots indicated almost similar values which is differently observed on the other two parameters. There was a strong positive relationship between MATLAB and Vicon for walking speed on the left foot (r(2) = 0.68) and a very strong positive relationship on the right foot (r(2) = 0.677). Based on Figure 6, walking speed showed almost similar correlation between left and right foots. This can be due to the consistent cadence during walking.

Vicon motion analysis may contribute more to accuracy of the data but needs skilled personnel as compared to the conventional gait analysis. However, in some cases, conventional gait analysis pattern was preferred due to its advantage that is easy to use in any suitable room, without having to change clothes and prepare markers like in motion analysis method [18]. It was conducted for analyzing gait pattern among children with autism.

Conclusions

The number of subjects used in this study were minimal and a greater number of subjects are necessary to obtain a particularly accurate result. Some ways to enhance the output of footprints are the use of digital camera to capture footprint instead of scanning them could save whole lot of time. A high-definition camera is highly encouraged so that it could capture the details of footprint to simplify the analysis process. 3D scanning device can direct capture the footprint on site and the usage of inkless tool is best to have a clear footprint without smudges.

Although motion capture system is the better option in studying gait analysis, conventional scanning method proven to be the next alternative to it. This could be observed from the achieved objectives. The walking parameters best to compare the data were stride length, step length, and walking speed. The results that were produced by image processing in MATLAB and Vicon Nexus were analyzed using statistical t-test. The comparison between conventional scanning method and motion capture system through footprint analysis showed that both methods have a significant strong positive relationship as the p-value < 0.05 and the Pearson coefficient were close to reach 1. The correlation hypothesis agreed to the alternative that there was a linear relationship between these two procedures. This study allows the user of both analyses to see the reliability of the results obtained and support the utilization of a cost-effective method for research conducted in Malaysia.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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