Evaluation of action sport camera optical motion capture system for 3D gait analysis

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Abstract. The high price of motion capture systems on the market has been a hindrance for many hospitals, health agencies and rehabilitation centers to acquire them. Due to its significance in gait analysis, the ITB Biomechanics Research Team has developed affordable motion capture systems since 2008. The advent of Action Sport Cameras (ASC) provide an affordable and portable alternative to the available motion capture systems. Hence, this work investigated the relative accuracy of an ASC based motion capture system. The well-established Vicon V8 with 10 cameras system is utilized in this study to evaluate the proposed ASC Mocap system. Simultaneous gait data acquisition is necessary to ensure valid comparison. Evaluation of the ASC based system was carried out by comparing the spatio-temporal and kinematics parameters obtained with that obtained with Vicon. Based on the parameters obtained, the 4 GoPro Hero 5 cameras system developed by the ITB Biomechanics Team’s is deemed to be suitable to be used in Gait Analysis, especially the spatio-temporal parameters that closely match the Vicon results. For the kinematic parameters, the results obtained while qualitatively similar, in many cases differ in magnitudes. This problem is currently is still under investigation and will be reported in future works.

Keywords: Motion capture system, gait parameters, 3D, action sport camera, Vicon, spatio-temporal, kinematics

1. Introduction

Gait is a personal characteristic of walking, a motion that is crucial in daily life of a person. Walking involves a complex motion to maintain balance and coordinate muscles to propel the body forward in stride. Since walking is an acquired skill it takes time for gait to mature. However, there are many possibilities that gait could deviate from normal walking. It is important to understand gait abnormality that a patient walk could be observed and recorded to obtain related gait parameters. Normal gait requires that many systems, including strength, sensation and coordination, function in an integrated fashion. Many common problems in the nervous system and musculoskeletal system will show up in the way a person walks [1].

Objective to measure or quantify a patient gait is commonly achieved by using optical motion capture (mocap) systems. Motion capture (mocap) is the process of recording the movement of objects in the form of objects or humans. This mocap technology originally came from the development of life sciences (biology) which was used to analyze gait [2]. Motion capture consists of a part that marks and
tracks the body and a part that converts that information into data that is useful for research and applications. The accuracy and precision obtained is determined by how the data is collected. This is because each motion capture system has different capabilities and limitations with regards to the accuracy and flexibility of data. Many motion capture systems are designed for indoor use, but several are effective and suitable for outdoor operation [3-6].

Today the process of recording the movement of these objects is widely and commercially used by VFX studios [7-8], sports therapists [9], neuroscientists, clinical specialists [10], biomechanists [11], validation and control of computer vision and robotics [2,12]. There are several motion capture systems already in circulation, such as Qualysis, Vicon, Motion Analysis, Xsens, and OptiTrack [13]. Which needs fixed setup, usually in a laboratory environment. Among commercial mocap systems, Vicon has higher resolution and has been certified according to standard that covers design, production and support for motion capture systems and includes software development for motion capture systems, measurement and analysis of three-dimensional structures [14-15]. Vicon has been taken as the gold standard in the mocap [16].

In efforts to provide affordable systems, ITB Biomechanics Research Team due to the needs in their investigations of gait and walking motion, have developed several optical motion capture systems. Initially with a single home-video camera for 2D gait analysis, and later 3D walking motion systems using two cameras [17-18]. On the other hand, the advent of Action Sport Cameras (ASC) and their affordability provide an alternative to the commercially available mocap systems. This work investigates the relative accuracy of an ASC based motion capture system. The proposed system consists of 4 (four) GoPro Hero 5 cameras and related data acquisition components. The well-established 10 cameras Vicon V8 is utilized in this study to evaluate the proposed ASC mocap system. Simultaneous gait data acquisition is necessary to ensure valid comparison. Evaluation of the ASC based system was carried out by comparing the spatio-temporal and kinematics parameters obtained to those of Vicon.

2. Methodology

Determination of the scale ratio needs to be performed in order to obtain comparable results for the two systems. Also, to enable result comparison, the data collection needs to be synchronized and taken at the same rate. To that end, the camera capture speed were set at 120 fps for both ASC mocap and Vicon systems. The data comparisons included one walking cycle for the left leg and the right leg obtained from a simultaneous data collection.

In the present work, due to its portability, the ASC mocap system was set-up at the Laboratory of Work System Design and Ergonomics, Faculty of Industrial Technology, Institut Teknologi Bandung, where the Vicon system is located. This would enable simultaneous data collection. The ASC based system set-up was determined by ensuring that the selected positions of the action cameras allow for recording of all markers on a subject while in walking motion at certain intervals. The direction of the black arrow in Figure 1 shows the direction of motion of the subject during the data collection.

![Figure 1 Experiment set-up](image-url)
The subject selected has a normal BMI, and does not have physical disabilities that could alter the gait or walking motion. Next, the subject's anthropometric measurements were taken to obtain necessary data input for both Mocap systems.

Marker placements on the subject were based on specific marker placement configurations for each system. Each active markers were placed according to ASC based system configurations and each passive markers were placed according to plug in gait marker placements set by Vicon. Markers placement on subject are shown in Figure 2. Modified markers were used as solution for handling markers that have overlapping position due to different type of markers and different marker configuration (Figure 3).

Before doing a trial or taking walking motion data on the subject. First, the calibration was carried out on the two existing motion analysis systems. The ASC Mocap system calibrates cameras by moving a 2-dimensional object and using Zhang camera calibration technique [19]. While for Vicon its active wand was employed to calibrate the cameras.

Before taking the data, the subject was asked to do walking exercises on the existing set-up. This is done so that the subject could walk at his preferred normal walking speed, and would not be hindered by the set-up or the equipment and markers that are attached to the subject. Data collection for the two motion analysis systems was then carried out simultaneously.
Determination of the global reference axis of the motion analysis system is needed to synchronize the origin of the coordinates systems used by the two systems. The global reference axis used by the author as a guide in data collection is the global reference axis of the Vicon motion analysis system. This reference axis has its origin at the middle of the two force-plates in the data collection set-up, as shown in Figure 4.

![Figure 4 Illustration of the global reference axis of the motion analysis systems](image)

Data processing from the results of data collection of the two motion analysis systems is carried out separately. Vicon has an established data processing system. While the ASC based mocap system employs the developed motion analysis system data processing software with an application interface as shown in Figure 5.

![Figure 5 Motion analysis application interface of ASC mocap](image)

Comparison of the kinematic parameters of the subject are focused on the sagittal plane. because in this field changes in the anatomical angle indicate the dominant visible and most significant human walking characteristics.

3. Results and Analysis
The subject selected was a 22-year old male, weighs 69.5 kg, and a height of 1.73 m with a BMI of 23.25. It was confirmed beforehand the absence of any disease or any dysfunction that could affect the gait motion. After the BMI calculation and clarification are done, the subject was deemed to have meet the requirements for data collection as a normal gait subject. The resulting gait spatio-temporal parameters and kinematic joint angles obtained by the two systems are tabulated in Table 1.
Table 1 Spatio-temporal gait parameters

| Variables            | Vicon | ASC |
|----------------------|-------|-----|
| Walking Speed (m/s)  | 1.04  | 1.08|
| Stride length (m)    | 1.24  | 1.27|
| Cadence (step/ min)  | 101.41| 101.41|
| Cycle time (s)       | 1.18  | 1.18|

Table 1 shows that the spatio-temporal data obtained in both systems are in agreement. The differences between the two systems are in the speed of the walking and the stride length. The difference that occurs between the spatio-temporal parameter results of the walking motion analysis system of the ASC-based mocap has an error of 3.09% on the spatio-temporal parameter data of the Vicon walking motion analysis system used as a reference. The error that occurs is relatively small when compared to the reference, so it may be stated that the 3D walking motion analysis system of the ITB Biomechanics Team has succeeded in obtaining the spatio-temporal parameter of human walking motion well.

The joint angular kinematics are joint angles in the sagittal plane, i.e. hip, knee, and ankle angles for both right and left foot. The comparison of results obtained by ASC mocap to that of Vicon are presented in Figures 6 – 8, along with gait reference database [20].

![Figure 6 Left Hip Angle (left) and Right Hip Angle (right)](image)

![Figure 7 Left Knee Angle (left) and Right Knee Angle (right)](image)
From the graphs obtained, the results of the processing of the Vicon mocap kinetics parameters can be used as a reference because it has a trend and the result timing that resembles the existing reference walking motion database. The results of the action camera mocap kinematics parameter data processing show data that have a trend and timing that is almost similar to the results of the Vicon mocap on the right hip angle, left hip angle, right knee and left knee of the subject although there are still differences in amplitude in some areas. The very significant difference in the results of the kinematic parameter data between the action camera mocap and the Vicon mocap is in the results of the angles of the subject's right and left ankles. The results obtained have relatively different trends / patterns and timing.

The difference in the results of the joint angle obtained is due to differences in human body modelling. The human body modeling of Vicon mocap system and action camera mocap system use three markers for the reconstruction of body segments such as calves and thighs. The modeling of the human body between the two systems differs in the foot reconstruction section where the Vicon mocap uses three markers that form a triangle for foot segment reconstruction while in the action camera mocap uses two markers forming a line pattern for foot segment reconstruction. This is the underlying cause of the considerable difference between the results of kinematics data processing of the right and left ankle angle of the action camera mocap and the Vicon mocap. Figures 9 (a) and (b) show the configuration of the human body modeling on the action camera mocap and Vicon.
4. Conclusion
After taking data and processing data for both mocap, it was found that the walking motion obtained was a normal walking motion. It is indicated that the results of the joint angle Vicon from the subject's walking motion are within the standard deviation range of the 3-dimensional walking motion data reference, so that Vicon can also be used as a reference in comparison.

Using Vicon as a reference in the analysis of existing walking motion results in an error of 3.09% in the calculation of each walking speed and stride length for ASC-based mocap system spatio-temporal parameters.

With this small error, it can be said that the ASC-based mocap yield accurate spatio-temporal gait parameters. However, for the calculation of joint angles, the Vicon mocap and ASC-based system have a fairly good value in calculating the hip angle and knee angle although there are still differences in amplitude and trend of the same walking motion. Calculation of ankle angle for both mocap has far enough results. This is presumably due to differences in human body modeling. From this, it may be concluded that the ASC mocap is still not very accurate in calculating the joint angles.

In future works, the ITB Biomechanics human body modeling mocap will be readjusted and several correction factors in the calculation of amplitude and trend joint angle.

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