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Improvement of three-dimensional motion analyzer system for the development of Indonesian gait database

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Abstract

Previously developed affordable three-dimensional (3D) Motion Analyzer System have been employed to obtain spatio-temporal gait parameters and 3D kinematics of upper body motion of both normal subjects as well as those with spinal abnormalities. However, occlusion problems have hindered the acquisition of the data. In this work, several modifications to the 3D Motion Analyzer System to improve its efficacy are proposed. First modification is the improvement in markers tracking module to overcome the occlusion problem, and the second one is automation of the subjects' anthropometry processing to minimize the possibility of error in data processing. The improved systems are then utilized to obtain 3D gait parameters and upper body motion during gait of 50 male and 50 female subjects as part of a continuous effort to establish Indonesia gait database. Prior to data acquisition, the subjects' anthropometry data and body posture are examined to ascertain normalcy. The subjects' weight and height are also assessed to ensure that they are in normal range according to Body-Mass Index (BMI) criteria. We have compared our results to those obtained in literature. The spatio-temporal and gait parameters of the subjects are in agreement with those found in literature. Furthermore, the improvements have been successfully implemented to overcome the occlusion problem and improve the program efficiency through the addition of automation of input data from a source file. Overall, the parameters obtained from this research show that the 3D Motion Analyzer system would serve the purpose of gait parameters determination well. Hence, the system has the potential for utilization as a medical diagnostic tool.

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Keywords: *Gait analysis, gait parameters, upper body motion, gait database, motion analyzer.*

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1. Introduction

Gait analysis is the study of locomotion, more specifically the study of human motion using the eyes and brain of observers, augmented by instrumentation for measuring body movement, body mechanics and the activity of muscle [1]. Human motion analyses have found many applications in various fields such as medical rehabilitation, sport science, product design and animation [2]. Previous researches on the development of affordable 3D Optical Motion Analyzer System have enabled the investigation of gait parameters of normal Indonesian people both for upper and lower body movement [3, 4, 5].

The Motion Analyzer System consists of detection, tracking, 3D reconstruction and post-processing modules. In order to obtain the gait parameters, the module must be run sequentially. However, there are still some weaknesses in the system such as markers occlusion because of upper extremities motion that hindered the camera view and manual processing of subjects anthropometry data that is prone to errors. Those weaknesses not only cause the data unable to be processed for gait parameters, but also may produce inaccurate result.

In this work, The Motion Analyzer system is improved to process data including the tracking of markers and automation of data reading. This improved system has been employed to obtain normal gait parameters for further development of 3D Indonesian gait database that could be the basis of future research.

2. Program Improvement

There are four modules utilized to process the data to obtain gait parameters, they are: detection, tracking, 3D reconstruction, and post-processing. The tracking module has the function to follow the displacement of each marker position in every frame. However, it can only track the marker position after the occlusion, in a specific range. This limitation makes the program unable to process the data in case of the occlusion area is greater than the specific range.

To overcome this problem, the program is modified by adding a feature that enables the tracking area to be expanded or narrowed. Another weakness of the program is in the post-processing module needed to calculate gait parameters based on the motion data of the markers. The anthropometric data of the subjects follows that of previous investigations [3, 4, 5] as shown in Fig. 1. These data are needed to construct the multi-body model, and were typed-in manually for each subject. Manual typing to input anthropometric data of the subjects are prone to error. To minimize this error, a program to enable automatic data reading was introduced. In addition, the automation process also eliminates time needed to input data. A source file containing the anthropometric data of many subjects may be read by the added subroutine for each subject.

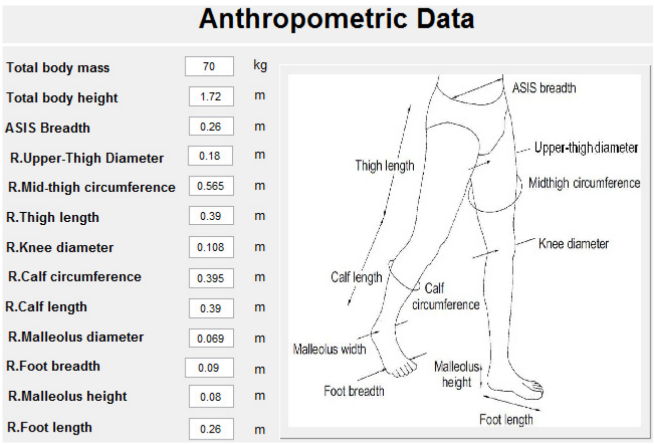

Fig. 1. Anthropometric data.

3. Participating Subjects and Procedure

After improvement of the system, it was used to obtain data of 100 normal subjects i.e., 50 male and 50 female. Subject normalcy are confirmed using procedure as described in [4]. The participating subjects are adult with ideal body weight according to Body-Mass Index (BMI) criterion as shown in Table1.

Table 1. Subjects Data

Data ($\frac{\text{Male}}{\text{Female}}$)	Average	Standard Deviation
Age (Year)	$\frac{20.65}{20}$	$\frac{1.47}{0.9}$
Body Weight (kg)	$\frac{62.04}{51.62}$	$\frac{7.16}{5.12}$
Body Height (m)	$\frac{1.7}{1.56}$	$\frac{0.07}{0.05}$
BMI	$\frac{21.4}{21.1}$	$\frac{1.8}{1.9}$

Fig. 2 presented the 3D optical motion analyzer system consisting of two 90 *fps* cameras, one computer and two walking paths. Each walking path is 2.5 m in length, and considered sufficient to record more than one gait cycle based on the average stride-length of 1.14 m for Indonesian male and 1.09 m for Indonesian female [4]. Markers' positions for the subjects were based on previous research [4, 5]. Sets of six and seven markers were used for upper body and lower extremities, respectively as pictured in Fig 3.

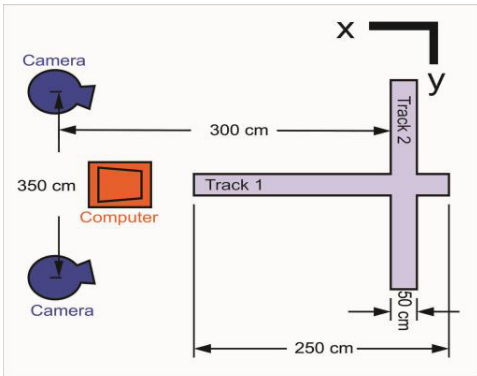

Fig. 2 Experimental Setup

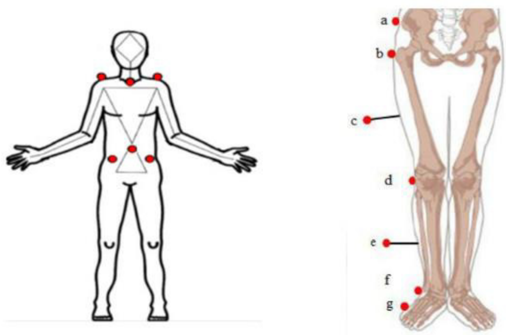

Fig. 3 Markers' positions (a) Upper Body (b) Lower Extremity

The subjects were instructed to walk normally in the walking paths and the cameras recorded their movement. The trajectories of the markers were then tracked based on their positions to determine segment motions. This gait study was conducted through the analysis of motion on three planes, i.e. sagittal, frontal and transverse; refer to Fig. 4 [6].

The sign convention used for the relative movement follows Sugiharto [5] after Vaughan et al. [7], where obliquity abduction motion have positive value and adduction have negative value. Moreover, internal rotation motion has positive value and external rotation has negative value as shown in Fig. 4.

Pelvic obliquity is positive when the pelvis left-side goes upward. While the rotation is positive when the pelvis had an external rotation (the right side of pelvis moves backward).

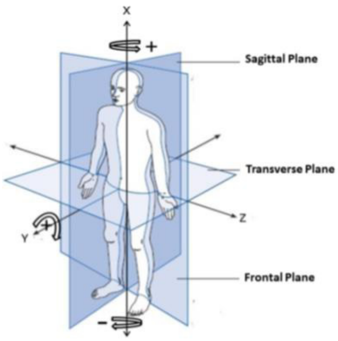

Fig. 4 Planes of analysis [6]

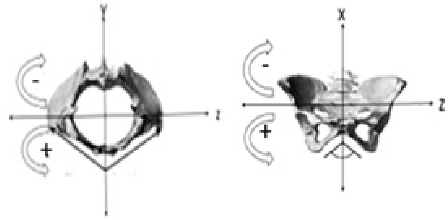

Fig. 5 Pelvic motion sign convention [7]

In this work, gait cycle starting point is defined differently for upper and lower extremity. In upper extremity, the periodic motion starting from right foot flat phase, where right pelvic position was at its extreme. Thus, during gait there are two extreme values of pelvis positions [8]. For lower extremity, gait cycle starting from right foot initial contact.

4. Results and Analysis

The average spatio-temporal parameters of the subjects are tabulated in Table 2. It may be seen that male subjects have longer stride length than female subjects. But on the other hand, female subjects have higher cadence. Other results obtained are kinematic parameters in the form of angular motion of body segments.

Table 2. Spatio-temporal Parameters

Spatio-temporal parameters	Cadence (step/min)	Cycle time (s)	Stride length (m)	Speed (m/s)
Male	90.12	1.34	1.18	4.1.1. 0.88
4.1.2. Female	4.1.3. 96.33	4.1.4. 1.25	4.1.5. 1.12	4.1.6. 0.91

4.2. Upper extremity gait parameters

Gait parameters for upper extremity are pelvic motion and relative motion of thoracal and pelvic as a function of gait cycle and the average values are compared to those of Sugiharto [5] and Konz [8] and shown in Figs. 6 – 9.

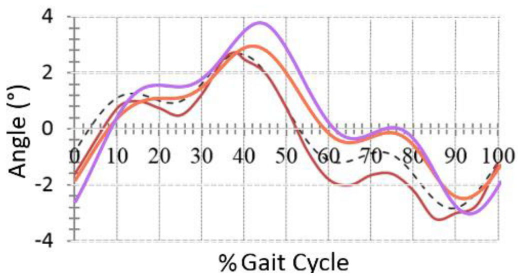

Fig.6 Pelvic obliquity (frontal plane)

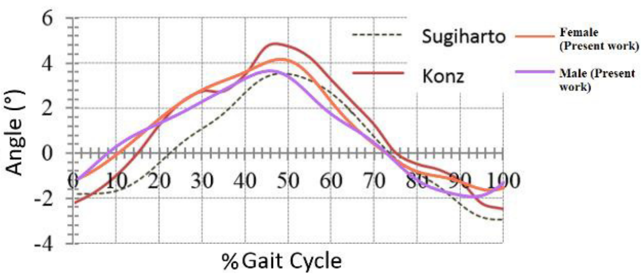

Fig.7 Pelvic rotation (transverse plane)

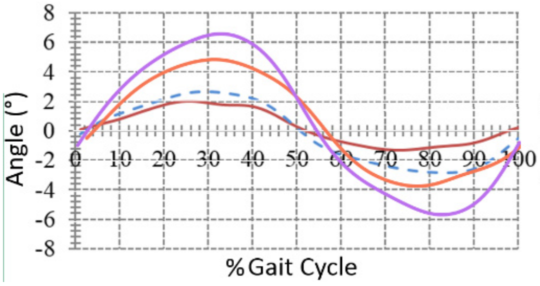

Fig.8 Thoracal-pelvic obliquity (frontal plane)

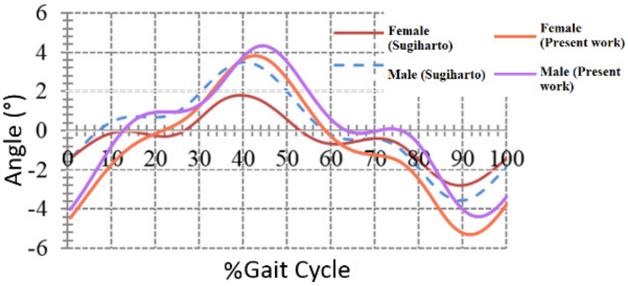

Fig.9 Thoracal-pelvic rotation (transverse plane)

The pattern and amplitude of pelvic obliquity and rotation are similar both for male and female subjects to those in [5] and [8]. It may be seen that subjects reach maximum value at 45% of gait cycle and that male subjects have higher value of pelvic obliquity than female subjects. On the other hand, female subjects have higher value of pelvic rotation. Thus, thoracal-pelvic relative motions, both for male and female subjects, have similar pattern with [5]. The ranges of motion/RoM (peak to peak) of thoracal-pelvic motions have higher value than those of [5] as shown in Table 3. This may be attributed to the different ways of walking for the subjects. In this research, subjects are instructed to walk with both hand swings freely and it makes the body to move without restraint compared with hands stay still at back of the body [5].

Table 3. Thoracal-Pelvic relative Range of Motion

Range of Motion ($\frac{Male}{Female}$)	Present work	Sugiharto	Difference
Obliquity	$\frac{11.9°}{8.4°}$	$\frac{5.5°}{3.3°}$	$\frac{6.4°}{5.1°}$
Rotation	$\frac{8.9°}{8.1°}$	$\frac{7.1°}{4.6°}$	$\frac{1.8°}{3.5°}$

4.3. Lower extremity gait parameters

Gait parameters for lower extremity are motions of hip, thigh, calf and foot as a function of gait cycle as shown in Figs.10 (a-c). Except for pelvic tilt, motions of both male and female subjects have similar pattern with Vaughan [7] as shown in Figs.10(b) and (c). From Fig. 10(b), pelvic obliquity of male and female subjects coincide but the RoM is lower compare to that of [7] as shown in Fig.10(c). On the other hand, the subjects have higher RoM of pelvic rotation as shown in Fig.10(c).

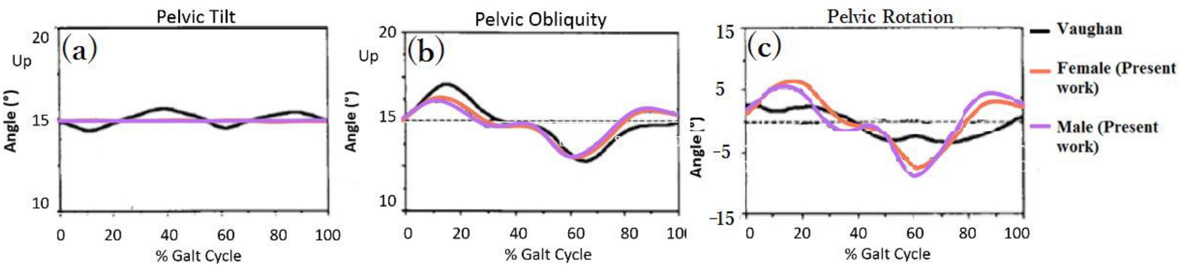

Fig.10 (a) Pelvic tilt (sagittal plane), (b) Pelvic obliquity (frontal plane), (c)Pelvic rotation (transverse plane)

The hip motions also have similar pattern with [7] as shown in Figs.13 (a – c). The hip motions on sagittal and frontal planes also have similar amplitudes. On transverse plane, the amplitude is similar and reach the peak at 70% gait cycle which slightly different with [7] that shows the peak at around 80% of gait cycle (Fig. 13 (c)).

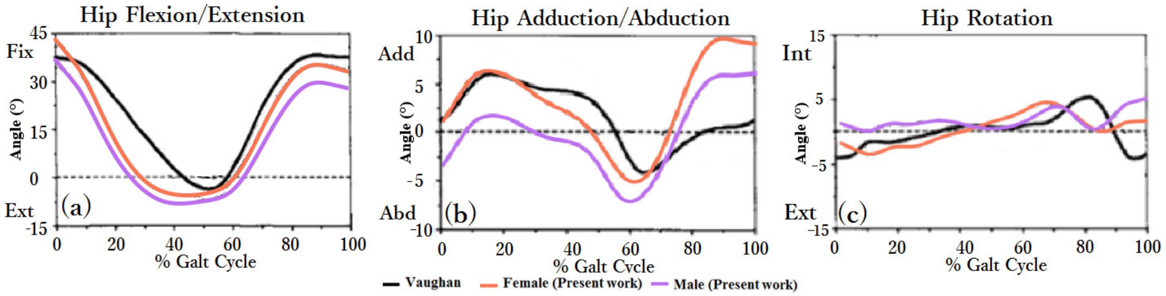

Fig.13 (a)Hip flexion/extension (sagittal plane), (b)Hip adduction/abduction (frontal plane) and (c)Hip rotation (transverse plane)

The knee motions are also found to be similar with [7], as shown in Figs.16 (a–c). On sagittal plane, the amplitudes remain constant until 50% gait cycle (Fig.16 (a)). It began to rise and reach the peak at 70% gait cycle then decrease until the end of the cycle. On frontal plane, the amplitudes steadily increase until 50% gait cycle and it began rise to maximum value at 80% gait cycle (Fig. 16 (b)). Knee rotation amplitude rises to 5° at 10% gait cycle and it slowly decrease until 60% gait cycle (Fig. 16 (c)).

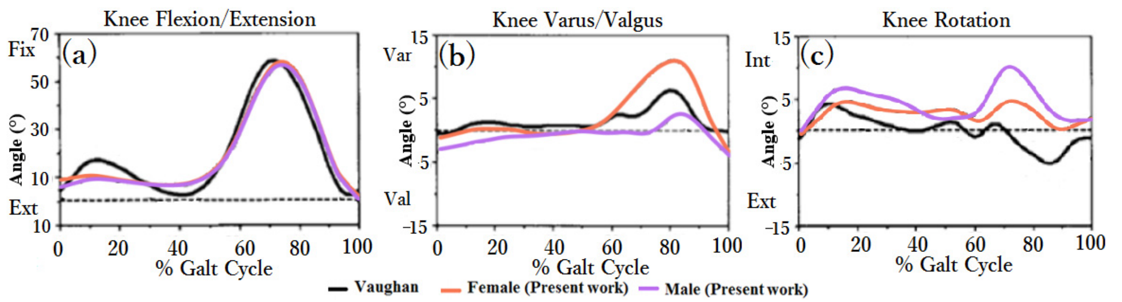

Fig.16 Knee flexion/extension (sagittal plane)Fig.17 Knee Varus/valgus (frontal plane)Fig. 18 Knee rotation (transverse plane)

The motions of ankle also have similar pattern with that of Vaughan [7] as shown in Figs. 19 (a) and (b).

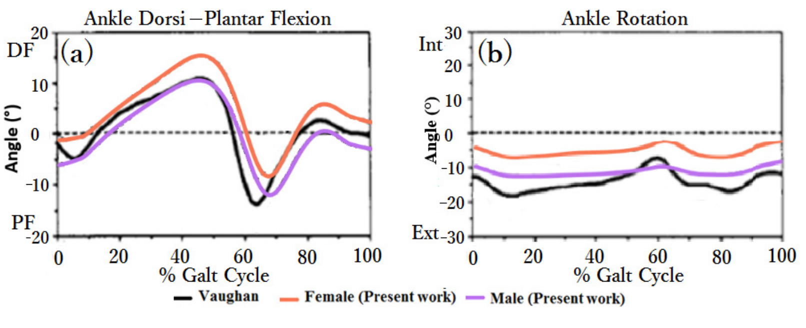

Fig. 19 (a)Ankle dorsi-plantar flexion (sagittal plane) and (b) Ankle rotation (transverse plane)

5. Summary and Conclusion

The improvements have been successfully implemented to overcome the weaknesses in the program. The modified tracking module helps to track the markers' positions during occlusion. By adding the ability to automatically read data from the source file, the potential of errors in manual typing of data is eliminated.

The gait parameters obtained were in good agreement with those found in literatures. Hence, the system has the potential to be used in gait analysis and further work on the establishment of Indonesian gait database.

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