DEVELOPMENT OF INDONESIAN GAIT DATABASE USING *2D* OPTICAL MOTION ANALYZER SYSTEM

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Abstract

In the present work, a previously developed optical motion-capture system combined with software for *2D* clinical gait analysis is utilized to obtain gait data of Indonesian subjects. The system consists of a video camera with a maximum speed of 90 *fps*, *LED* markers, PC and technical computing software, which are developed for tracking markers attached to human body during motion and to calculate kinematics and kinetics parameters of human gait. This work presents only the kinematics gait parameters of 212 participating subjects obtained by the developed optical 2D motion analyzer system and software. Prior to measurement, the body posture of each subject is evaluated to ensure normalcy. The subject is instructed to walk in a specially-arranged measurement area. The spatiotemporal gait parameters such as stride-length, cadence, cycle-time, and speed as well as joint angles, are evaluated. The gait data of the 212 participating subjects that has been collected are compared to data available in literature. Based upon favorable comparisons, the data presented in this work could serve as the basis for the establishment of Indonesian normal gait database. Future works involving more participating subjects and comparative analysis to abnormal gait is deemed necessary and should be useful to assist physicians in diagnosing, and planning the rehabilitation program for the patients.

Keywords: Gait analysis, Gait parameters, Motion analyzer system, Gait database

Introduction

The investigations of human motion have been widely employed in various fields, from medical diagnostics, physical therapy, and sport science [1-5]. Optical motion analyzer systems have been widely used to study human motion, most notably in gait analysis, for medical rehabilitation purposes [5].

Unfortunately, the availability of the system for medical diagnostics at most Indonesian hospitals is almost non-existent. Furthermore, there is no data for normal gait for Indonesians. While many commercially available systems would contribute to the diagnostics and establishment of Indonesian gait database, the cost is still prohibitively expensive for most hospitals. To overcome the lack of availability of the system, the authors developed an affordable and integrated *2D* optical motion analyzer system utilizing a 25 *fps* home video recorder and PC-based data acquisition system. Software for kinematic and kinetic analyses was developed and LED markers were used [6]. Later, a 90 *fps* camera was employed to improve accuracy, and the algorithm was further developed to overcome the occlusion problem of the markers [7]. The system is further improved by utilizing the Direct Linear Transformation (DLT) method in the calibration process, and used to determine *2D* gait parameters of 60 subjects to initiate the development of Indonesian walking database as reported by Mahyuddin et al. [8]. Based on the markers position during walking, and utilizing a multibody kinematic model [9], the spatio-temporal gait parameters as well as the joint angles are evaluated. To validate the system, the results in [8] are compared to those of Koreans data investigated in [10] as well as American data [1, 11]. The results in [8] also compare favorably to available data, and provide a glimpse into the characteristics of Indonesian gait. Also, it was concluded that the developed 2D Optical Motion Analyzer system is sufficiently reliable for gait parameters determination.

Based on the findings in [8], this research aims to develop Indonesian gait reference data by using the 2D motion analyzer system that consists of an image recording and processing system, and a computer program for kinematics and kinetics analysis of human gait. In this system, the motions of LED markers placed on a subject's anatomical landmarks are captured by a camera in a specially arranged measurement area. Obtained digital image are then transformed into the 2D coordinates of the markers that are subsequently employed in the kinematics and kinetics analyses of the subject motion. The analyses yield spatio-temporal parameters such as stride length, cycle time, cadence, and walking speed, as well as joint angles, and working forces on the foot.

Collaborations with partners in *Medical Rehabilitation Department of RSHS* (*Hasan Sadikin Hospital*), Bandung, helped to improve the system for ease-of-use, and in data collection for initializing gait database of Indonesian people based on sexes and age-groups. Input on the proper way of measuring the anthropometric data as well as the needed parameters have also tremendously improved the system. Experiments were conducted at the *Hasan Sadikin Hospital* to obtain gait data of 102 male and 110 female subjects from various age-groups using the developed *2D* Optical Motion Analyzer System. In this work, the results presented are limited to spatiotemporal and kinematics parameters only.

Database obtained will be useful for the medical service institution, especially in the field of medical rehabilitation, where by using the obtained normal gait data as reference, the system could assist physician in diagnosing, and planning the rehabilitation program for the patient. The system could also be utilized to evaluate the prosthesis design that suit the anthropometric of Indonesian people.

For completeness, the discussions presented in Mahyuddin et al. [8] are briefly reviewed in the following sections, while the initial results obtained to establish the initial database are presented in subsequent sections. The results indicate that the system developed while simple and affordable serve as an expedient tool to obtain gait data and has the potential to be further developed into a medical diagnostic tool.

Spatiotemporal and Kinematics Parameters

The gait cycle is the time interval between two successive occurrences of one of the repetitive events of walking. Starting from initial contact of the left foot, for example, followed by various events, the cycle continues until the left foot makes contact with the ground. The duration is known as cycle-time, consisting of stance-time and swing-time [1]. The motion analyzer system yields coordinate data of markers for evaluation of *stride-length*. Figure 1 depicts the stride length define as the distance between two position of the same foot, consisting of right- and left-step lengths. Another parameter is cadence, defined as the number of steps taken in a given time, and is inversely proportional to cycle time. The walking speed is evaluated based on the stride length and cadence.

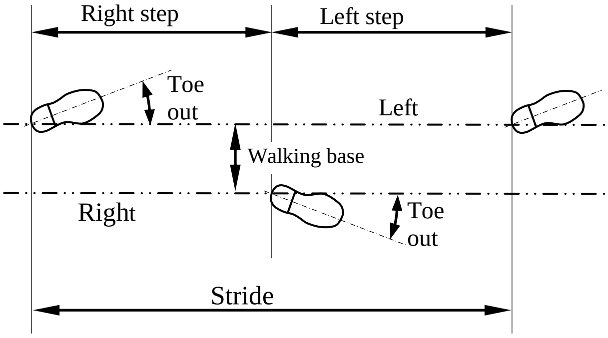

Figure 1. Stride-length

Figure 2 depicts the multibody human walking model consists of 5 bars that are employed to evaluate the kinematic and kinetic parameters by inverse dynamics [9]. The markers to be used in the analysis are placed on ankles (A and F), knees (B and E), and hip (F). However, in this work only the hip (θ_3) and knee (θ_2) angles are presented.

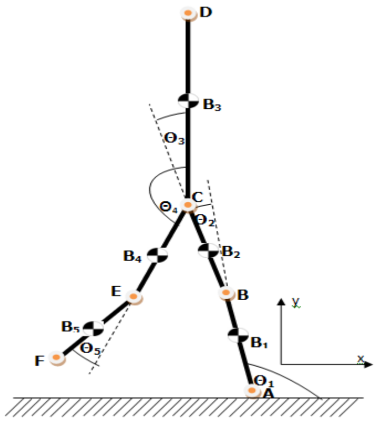

Figure 2. Human body model [9]

Motion Analyzer System

The system utilized is the one employed in [8], and is illustrated in Figure 3. In general the system consists of both image recording and processing system, and a computer program for kinematics and kinetics analysis of human gait. Several notable improvements from the previous system developed by the authors [6, 7] are the use of a 90 *fps* camera and *DLT* method in the calibration process.

To acquire motion data, the *LED* markers are attached to anatomical landmarks of the subject and their movements are then recorded by a 90 *fps* video camera *(Sentech STC-CLC33A)* connected to an image acquisition card (*NI PCIe-1430*) installed in a PC to obtain captured video data. The output from the card is then saved to the hard drive as a series of image files representing 90 Hz data of the subject motion. Each image file is then analyzed to determine the *2D* coordinates of the markers as a function of time, based on image *binarization* method (*thresholding*). By using the developed software, spatio-temporal parameters such as stride length, cycle time, cadence, and walking speed, as well as joint angles, and working forces on the foot could be obtained.

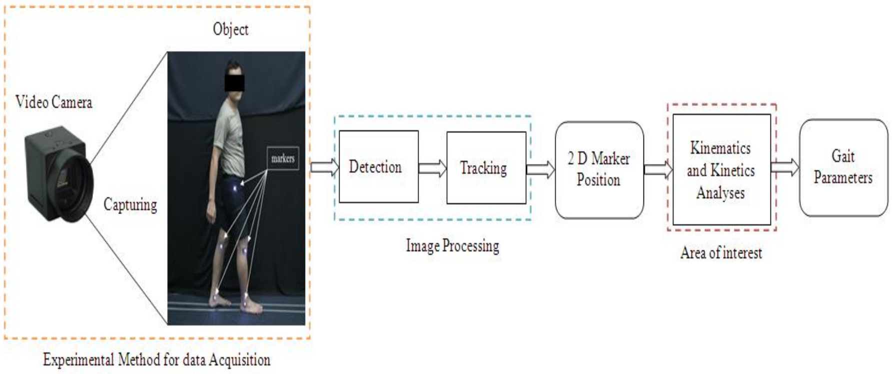

Figure 3. *2D* optical motion analyzer system

System Setup and Calibration

The experimental setup and recording environment at the *Medical Rehabilitation Dept., Hasan Sadikin Hospital* is illustrated in Figure 4. The video camera is located 4 m orthogonal to a 3.5 m walking path. Prior to data recording, the system is calibrated by using two calibration rods with four markers using the DLT method. The DLT parameters are then used to convert the markers location on the observation plane into its 2D coordinates.

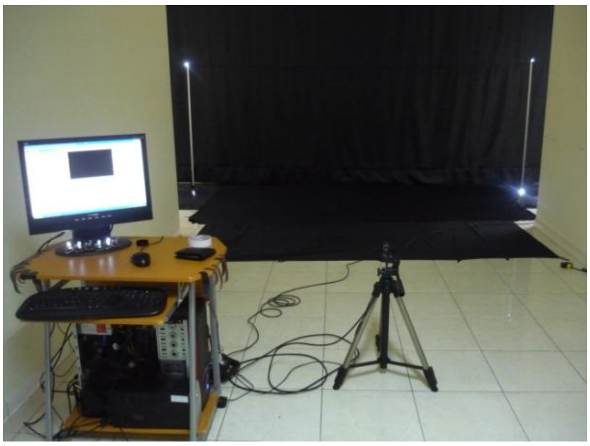

Figure 4. Setup and calibration

Image Processing

A program written in *MATLAB* has been developed to detect and track the marker's position over time. Image *binarization* method (*thresholding*) is employed for the detection process of markers. For tracking the markers' movement, the least distance method is applied. The image processing code is developed using *MATLAB*. By using calibration data (*mm/pixel*), the coordinates of markers in the image plane are then converted into the world coordinates. Finally, from the *2D* data, and measured parameters such as dimensions and weight of the body, kinematics and kinetics analyses are performed. A special technique has also been proposed to overcome the occlusion of markers from the camera's view by the other part of body during movement. For detailed explanation of this process, the reader is referred to [7, 12].

Participating Subjects and Data Collection

The *2D* Optical Motion Analyzer is employed to collect normal gait data of 102 male and 110 female subjects from various age-groups and sexes as summarized in Table 1. The age classification follows that of Whittle [1]. People in the age-group 18 – 49 are considered to have established gait, while beyond 49 years of age people tend to have degenerative aspects that affect gait parameters. Table 2 presents the mean age and anthropometric data of the male and female subjects within the 18-49 age-groups; which is the bulk of the participating subjects, along with the standard deviation.

Table 1. Participating Subjects, based on Sexes and Age-Groups

Age-group	Male	Female	Total
<15	22	5	27
15-17	11	5	16
18-49	**58**	**50**	**108**
50-64	6	**39**	45
>64	5	11	16
Total	**102**	**110**	**212**

Table 2. Age and Anthropometric Dimensions of Subjects in the 18-49 Age-Group

Variables	Male Mean(SD)	Female Mean(SD)
Age (year)	31.84(7.87)	34.84(9.89)
Height (m)	1.65(0.07)	1.55(0.07)
Weight (kg)	61.96(12.15)	55.69(9.58)
Leg length (m)	0.85(0.07)	0.84(0.06)
BMI	22.63(3.87)	23.29(4.31)

Similar procedures as the ones described in Mahyuddin et al. [8] were followed. Before the measurements, the body posture and body mass index (*BMI*) of each subject is evaluated to ensure normalcy. To check posture normalcy, the shoulder and the back of each subject are observed (see Figure 5). If it is unsymmetrical, it will be considered abnormal, whether having *scoliosis* or *lordosis*. The length of each leg is also measured to check whether the two legs are having the same length (see Figure 6). A difference of more than 2 cm will be considered abnormal. Height and weight of each subject are measured to calculate the *BMI*, which is considered normal if the value is between 18.5 and 24.9. Only a subject with a normal posture and BMI will be included in the normal gait measurement.

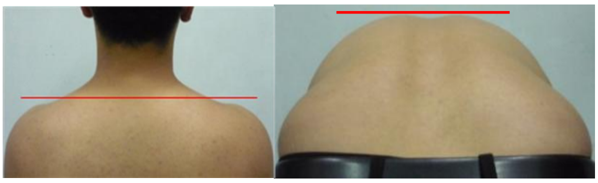

Figure. 5 Posture normalcy check

Figure 6. Length measurement of the leg

As in Mahyuddin et al. [8], each subject is asked to wear a dark legging, and then 5 *LED* markers with a diameter of 8 mm are attached carefully on several anatomical landmarks: *Greater Throcanter* (at hip), *Lateral and Medial Femoral Epicondyle* (at knees); and *Lateral and Medial Malleolus* (at ankles). The anthropometric measurement is then conducted to measure thigh length, calf length, and *malleolus* height. These data will then be used as input in the Motion Analyzer software to calculate the *2D* gait parameters.

Results and Discussion

Following are several results obtained from the measurements of the subjects. Since the present interest is more on the characteristics of normal walking of Indonesian people, only the spatio-temporal and kinematics parameters of the subjects are presented. The results are compared to those obtained from literature.

Spatio-Temporal Parameters

The spatio-temporal parameters of the larger subjects population (18 – 49 age-group), i.e. cadence, stride length, walking speed, and cycle time, are summarized in Table 3. The two right-most column are range values of gait parameters of normal male and female subjects ages 18 – 49 years from Whittle [1]. Comparing male and female subjects, the results show that while female subjects have shorter stride length, but slightly higher *cadence*. As a result, on average, the walking speed of female is slower than male subjects. The shorter female stride length may be attributed to the fact that the female subject are shorter (Table 2). But with similar leg length between male and female subjects, a more approriate explanation would be that the male and female gaits are different.

In addition, it may be seen that, the Indonesian subjects have shorter stride length and slower cadence compared to the range given in Whittle [1]. While the shorter stride length may be attributed to the relatively smaller stature of the Indonesian subjects, the slower pace may be an indication of gait characteristics particular to Indonesian.

Table 3. Spatio-Temporal Gait Parameters of Subjects in 18 – 49 Age-Group

Variables	Male		Female		Whittle, 2007 (range); 18 - 49	
	Mean	SD	Mean	SD	Male	Female
Walking speed	1.09	0.11	1.02	0.12	1.10-1.82	0.94-1.66
Stride length (m)	1.20	0.08	1.11	0.10	1.25-1.85	1.06-1.58
Cadence	109.29	7.84	110.36	9.78	91-135	98-138
Cycle time (s)	1.10	0.13	1.10	0.14	0.89-1.32	0.87-1.22

As another example, the spatio-temporal parameters of female subjects in the 50 – 64 age-group, that has fairly large participating subjects, are shown in Table 4. It may be seen that the values are within the ranges given by Whittle [1]. While the ranges are relatively wide, the spatio-temporal parameters of the 39 female subjects in the 50 – 64 age-group all fall within the ranges. It is worth noting however, that the average walking speed and stride length of Indonesian female subjects within this age-group tends toward the lower end of the spectrum given by [1]. Once again, this may be due to the relatively smaller physical stature of the Indonesian subjects with an average height of 1.49 m.

Table 4. Spatio-Temporal Gait Parameters of Female Subjects in 50 – 64 Age-Group

Female Age: 50 – 64 Variables	Mean	SD	Whittle, 2007 (range)
Walking speed (m/s)	0.97	0.12	0.91 – 1.63
Stride length (m)	1.06	0.11	1.04 – 1.56
Cadence (steps/min)	109.41	6.80	97 - 137
Cycle time (s)	1.10	0.07	0.88 – 1.24

For comparison of gait parameters for various age-groups, Figure 7 – 9 present the spatio-temporal parameters of the subjects from various age-groups. While Figure 7 compares the stride-length and walking speed of the Indonesian male and female subjects, Figure 8 and 9 compare the cadence of the Indonesian male and female subjects to the ranges given in Whittle [1], respectively. The walking speed is computed from the stride length and cadence.

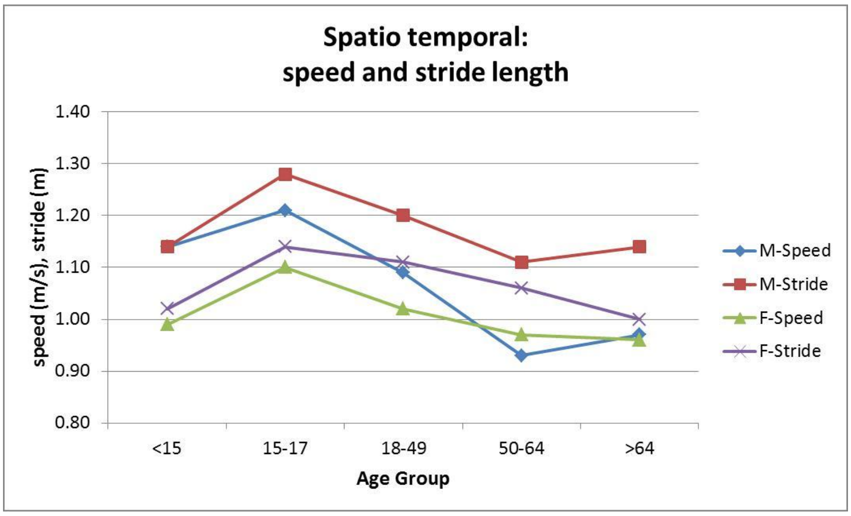

Figure 7. Comparison of stride-length and speed of various age-groups

It may be seen from Figure 7, as with the 18 – 49 age-group that, comparing M-Stride to F-Stride curves, in general the male subjects have longer average stride-length. Also, for both male and female subjects, the stride length of the 15 – 17 age-group is longer than that of the <15 age-group. But, the stride-length becomes shorter with increased age, with the exception of the male subjects in the > 64 age-group. However, the relatively small numbers of male subjects in the 50 – 64, and > 64 age-groups may contribute to this discrepancy. More data is needed for a more thorough analysis of normal gait.

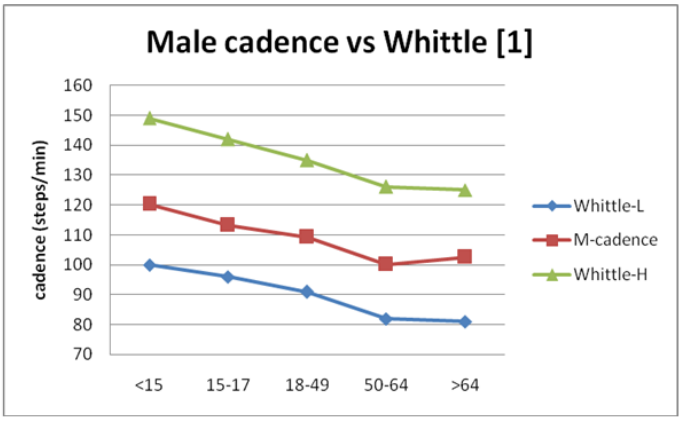

Figure 8. Male subjects' cadence vs. Whittle [1]

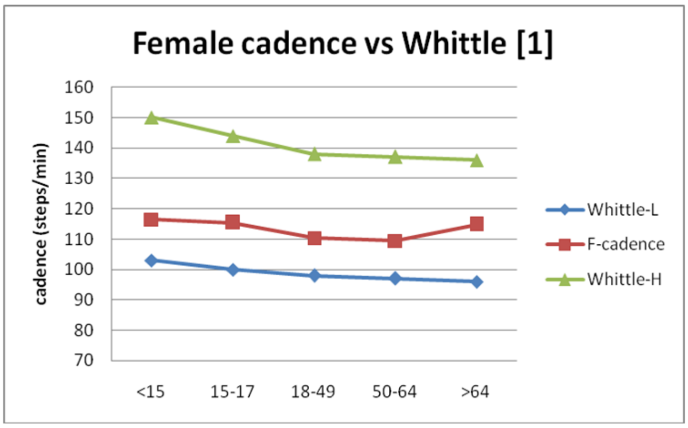

Figure 9. Female subjects' cadence vs. Whittle [1]

Figure 8, showing a decreasing trend of the male subjects' average cadence, is in agreement with that given by Whittle [1]. Furthermore, the cadences of the male subjects are within the range, as indicated by the low values (Whittle-L) and high values (Whittle-H) lines. However, it is worth noting that the average cadence of subjects over 64 is higher than those in the 50 – 64 age-group. Similar observations could also be made for the cadence of the female subjects shown in Figre 9, along with the lower and upper bound of the range given by Whittle for female subjects. The cadence of female subjects in all age-groups also fall within the range given, even though the decreasing trends is not as pronounced as that of the male subjects.

Comparison of the Indonesian subjects' stride length to the normal ranges given by [1] are presented in Figure 10 and 11. In Figure 10, the average stride length of the male subjects tends to the lower bound of the ranges given in [1]. Furthermore, the trend while showing similarity, does not match the low- and high-value curves of the ranges. Most notably, the difference is that the longest average stride-length for Indonesian male subjects belongs to the 15 – 17 age-group, not the 18 – 49. On the other hand, the average female subjects stride length for various age-groups show a trend that better matches the lower values of the ranges given in Whittle [1]. But, as with the male subjects, the largest average is also found to be that of the 15 – 17 age-groups. While this tendency is observed, a more comprehensive database is needed to formulate the normal gait characteristics of Indonesian people.

Figure 10. Male subjects stride length vs. Whittle [1]

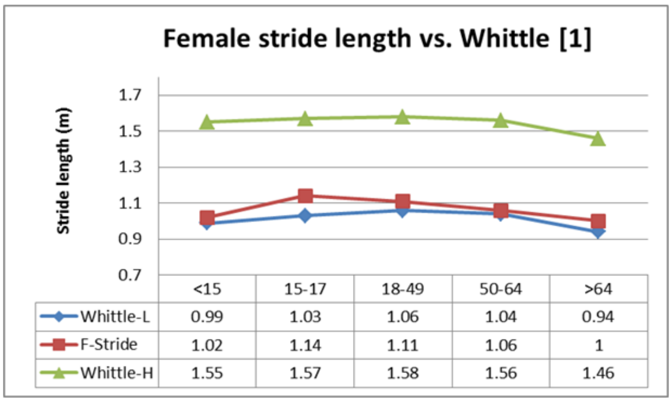

Figure 11. Female subjects stride length vs. Whittle [1]

Kinematic Angular Parameters

The kinematic parameters in the form of maximum, average and minimum of knee-angles for male and female subjects in the 18 – 49 age-group are presented in Figure 12. While that of the hip-angles of male and female subjects within the same age-group are depicted in Figure 13.

Similar motion patterns and excursions are observed for both male and female subjects. Comparison with available joint angular motion data in literature [1, 4, 10] as well as those presented in [8], show the results are in agreement. Most motion patterns and excursions are similar to those of normal gait data of previous studies [1, 3, 7, 9, 10]. Results for other age-groups show similar tendencies. Thus, the data may serve as the initial basis for the establishment of normal Indonesian gait.

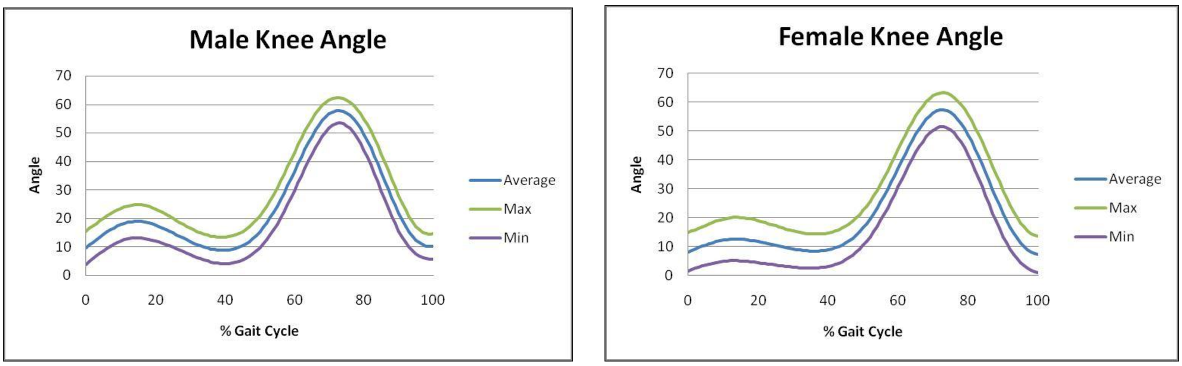

Figure 12. Male and female knee angles for age-group 18 - 49

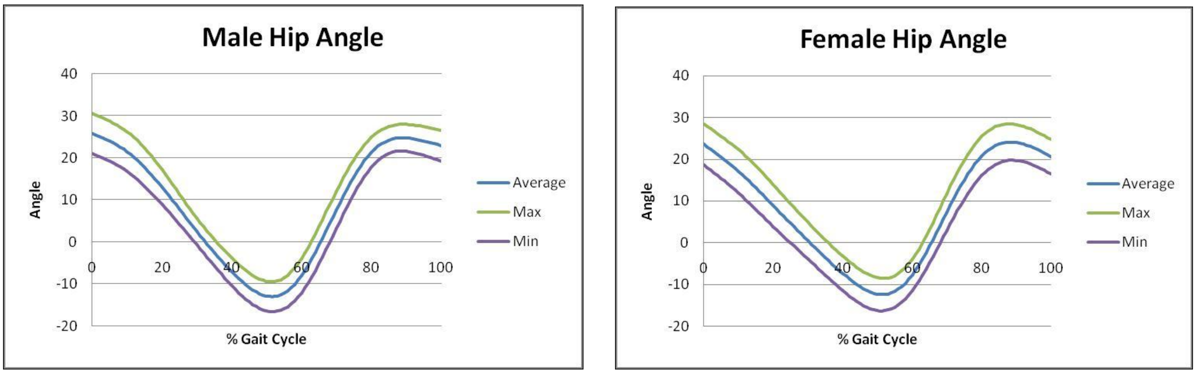

Figure 13. Male and female Hip angles for age-group 18-49

While not shown in this work, the spatio-temporal parameters for the other age-groups also show similar tendencies. Thus, even though still limited in numbers, the data obtained could serve as an initial database for an Indonesian gait reference.

Conclusions

In this work, an optical motion analyzer system had been employed to obtain *2D* gait parameters. The results are in the form of normal gait database of Indonesian people. The data are comparable to available normal gait data. This indicates that the initial development of the database is quiet successful. The obtained data should serve as initial database, while the system developed could be further utilized in the enrichment of the database as well as for clinical purpose by measuring and analyzing abnormal gait. The resulting kinematics and kinetics parameters are useful in determining therapy protocol as well as keeping track of the patient's progress. Hence, the system has the potential to be further developed into a medical diagnostic tool.

While an effort to develop an Indonesian normal gait database has been attempted, it is realized that formulation of "standard" normal gait would require more participating subjects to obtain comprehensive data. Analyses on the gait parameters, as well as comparison to abnormal gait, would be needed prior to establishing normal gait characteristics. In addition, due to the simplicity of the kinematic model employed in this study, the parameters obtained are somewhat limited. Therefore, at present a more complex *2D* kinematic model of human walking is employed to obtain more gait parameters, such as ankle angle, and more accurate spatio-temporal parameters.

Present works also include the development of an affordable and integrated optical motion analyzer for *3D* gait analysis [13, 14]. While gait information on the *sagittal* plane is deemed most important, a *3D* kinematic model for kinematic and kinetic analyses would yield information on the frontal and transverse planes.

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