KINECT-BASED SPATIOTEMPEORAL GAIT ASSESSMENT FOR FILIPINOS VIA CROSS CORRELATION CALCULATION USING MATLAB

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***Abstract* – The gait of a person is a significant marker of well-being, with applications ranging from observation, diagnosis, tracking and rehabilitation. The use of gait evaluation has been limited. Current gait analysis technologies, for example, a facility or a laboratory, are either expensive, invasive, or require well-controlled conditions. This paper establishes a normative walking gait database that will serve as reference for comparing the subject's gait and the normalize gait. Test subjects that were recruited in the study have no history of any injury or gait abnormality and were divided according to age, gender, and Body Mass Index (BMI). We present a gait analysis system that is affordable and non-intrusive. Our system is based on the Kinect sensor and thus can extract comprehensive gait information from all parts of the body. Beyond standard stride information, we measure using spatiotemporal parameters. We further improve over existing work by making a system that store and analyses the subjects' gait, it also compares different gaits to distinguish the variations from the normal gait and the subject's gait.**

***Index terms* -- Gait Analysis, Normative Walking Gait, Gait Abnormality, Kinect sensor**

I. INTRODUCTION

Assessment in gait condition, diagnostic signs and symptoms are acquired and interpreted to determine the type and extent of gait abnormality. Symptom is considered as the injured individual's perception of the problem, while a diagnostic sign is an objective, measurable, physical finding regarding an individual's condition [1]. In identifying the root cause of physical problems such as pathological gait, gait analysis plays an important part [2].

Gait analysis involves observing patterns to scientifically determine abnormal or atypical movement patterns while walking or running [3]. Gait analysis is a critical tool in accurate diagnosis of some injuries especially in the field of sports. High stresses are produced within the joints during some sports activities when there is an abnormality or impairment in the movement that results in symptoms of injuries [4].

Results from gait investigation give information to evaluation of an assortment of stride related abnormalities, paying little heed to the seriousness of injury and absence of versatility of the patient. With the point of rehabilitating the patient to his most significant level of health, a treatment plan that is explicitly intended to concentrate on influenced parts is made after conclusion [5]. Gait reference data are essential in determining the nature and severity of gait deviations in injured individuals and in helpful evaluation of the effect of clinical treatment [6]. This is used as a comparison between an impaired and a healthy unimpaired individual of same age, gender, and Body Mass Index (BMI). These normative data commonly come from control groups of studies involving pathological gait patterns. These are very useful indicators of gait abnormality and even the extent of abnormality without necessarily indicating the cause of problem [7].

Irregularities in the gait pattern of a person often stipulate symptoms of pathological gait. To identify pathology and track recovery, univariate parameters, such as step length, walking speed, stance, and swing time, are used to characterize asymmetries with symmetry indices and ratio [8]. Several corrective treatments are proposed that aims to control and improve the efficiency of pathological gaits based on the data obtained from gait analysis and clinical evaluation [9]. Gait patterns generally vary with ethnicity, racial, and cultural factors. Studies show that the use of other ethnicities' gait parameters can lead to both misdiagnosis and misinterpretation of clinical problems [6].

Asian and Non-Asian countries have different values on parameters that includes stride length, walking speed, vertical ground reaction force, step length, and step frequency [6][7][12]. Differences in parameters are also present between Asian countries which include cadence and stride length [6][13]. This shows that existing gait reference data are not generally applicable to all ethnicities because of the differences in gait kinematics. Filipinos, as part of the Asian group, embody unique gait characteristics. Therefore, there is a need for an ethnicity-specific walking gait database.

To perform accurately on gait analysis for Filipinos, a gait database for Filipinos was developed by utilizing a portable motion capture system the MS Kinect which consists of infrared projector, RGB camera and an IR camera. The Microsoft Kinect V2 is a camera-based sensor primarily used to directly control computer games through body movement. The Kinect tracks the position of the limbs and body without the need for handheld controllers or force platforms. Use of a depth sensor also allows the Kinect to capture three-dimensional movement patterns [14].

MS Kinect was used as an alternative low-cost gait analysis method. This research also aims to validate the capability of the sensor used and to assess the accuracy of Microsoft Kinect V2 sensor for the assessment of walking gait parameters of Filipinos. The outline of the paper is as follows: Section II discussed the methodology of the research which tackles about how the study was done, from the test subjects and experimental set-up, up to the process on how the data gathered were analyzed. Section III presented the data and results gathered from the study. Section IV discussed the trends of the parameters obtained. And lastly, Section V summarized the entire study and included the possible improvements of the research for the future work.

II. METHODOLOGY

The study was divided into six phases namely: the gathering of test subjects, setting up of the equipment, validation of the equipment, the actual testing or the gathering of data, the analysis of the gathered data, and the drawing of conclusion from the data based on statistical analyses

A. Subjects

The study involved the analysis of the natural gait of healthy Filipino men and women. To analyze Filipino gait characteristics using MS Kinect, 70 male and 40 female consenting subjects were recruited in the study. To categorize the different test subjects according to their gender, age, and BMI, the height and weight of each subject were measured. The age of each subject was also recorded. Table I shows the measured data.

TABLE I
MEAN (SD) OF AGE IN YEARS AND ANTHROPOMETRIC DATA WHICH INCLUDE HEIGHT IN METERS, WEIGHT IN KILOGRAMS, AND BMI IN KG/M^2

	Male Mean (SD)	Female Mean (SD)
Age (years)	1.03	1.15
Height (m)	0.05197817	0.05224407
Weight (kg)	10.3445159	6.54156726
BMI	3.4687902	2.3989945

The test subjects were at their early 20's or late teenage years – ages at which the development of gait is complete (considered to be of an adult) yet no degenerative factors related to aging are present [6]. In gathering the subjects of the study, a criterion that subjects should have no history of musculoskeletal, neuromuscular, neurological and any other type of abnormality concerning the lower part of the body that may cause abnormal gait [15].

B. Experimental Setup

Subject are composed of 21 males and 9 females with different weight and height. The subjects are asked to walk to the position of the Kinect. This is continued until all the height of the tripod are utilized. After the trial the proponents concludes that for the effective distance the tripod height must be 440cm producing a range of 1.5m being the minimum effective distance and 4m being the maximum effective distance, the group will be using the 3.5m – 4m distance in order to have a wider walking area for the assessment.

C. Data Collection

A Microsoft Kinect V2 camera was used to gather data using Software Development Kit (SDK) and a custom-built software created on Microsoft Studio. Microsoft Kinect camera was composed of an infrared sensor, RGB camera and IR camera to track human gait movement [16]. Microsoft Kinect's SDK provides tool used necessary to startup Kinect enabled applications for Microsoft Windows [18]. Custom-built software was used to track and acquire skeletal joint position data of the subjects. These joints are represented as X, Y, Z in the 3D coordinate system. As the subject walks on the pathway, key points are recorded for each frame the sensor grabs. Each key point that is represented by the coordinates corresponds to its distance from the (0, 0, 0) point in space. These key points are important in calculating different gait parameters. The skeletal data acquired at a rate of 30 frames per second is the output of the Kinect system saved in an external file [16].

Gait parameters (spatial and temporal parameters) and relevant angles were calculated in MATLAB using Euclidean distance formula and cosine law, respectively [17]

Euclidean formula:

$$d(i,j) = \sqrt{(Xi - Xj)^2 + (Yi - Yj)^2 + (Zi - Zj)^2} \quad (1)$$

Cosine Law:

$$A = \frac{Xi - Xj}{\sqrt{(Xi - Xj)^2 + (Yi - Yj)^2 + (Zi - Zj)^2}} \quad (2)$$

$$B = \frac{Yi - Yj}{\sqrt{(Xi - Xj)^2 + (Yi - Yj)^2 + (Zi - Zj)^2}} \quad (3)$$

$$C = \frac{Zi - Zj}{\sqrt{(Xi - Xj)^2 + (Yi - Yj)^2 + (Zi - Zj)^2}} \quad (4)$$

$$\theta = cos^{-1}(\frac{B^2 - A^2 - C^2}{2AC}) \quad (5)$$

D. Data Analysis

Data obtained from Microsoft Kinect v2 were exported to MATLAB (R2018a, The MathWorks Inc., Natick, MA, USA) for calculation of the biomechanical parameters. The spatiotemporal parameters were established [20].

a. Spatiotemporal Analysis

Spatiotemporal parameters are divided into two branches: the first one is the spatial parameter or also known as the distance parameter while the second one is the temporal parameter or also known as the time parameter. One of these spatial parameters is step length (Table II). On the other hand, temporal parameters include step time, stride time, swing time, stance time, speed, and cadence (Table II). The timing of heel strike (HS) and toe off (TO) are essential in determining various spatiotemporal gait parameters. The timing of each heel strike was obtained by measuring the maxima of the ankle to ankle distance while the timing of each toe-off was obtained by measuring the maxima of the foot to foot distance [22]. Table II shows the corresponding definition for each spatiotemporal parameter.

TABLE II
OPERATIONAL DEFINITIONS FOR SPATIOTEMPORAL PARAMETERS

Spatiotemporal Parameters	Operation definition
Spatial Parameters Step length (m)	Distance between the contact points of the right and left feet
Temporal Parameters Step time (s)	The time between the contact points of the right and left feet
Stride time (s)	The time between the initial and consecutive contact points of the same foot
Swing time (s)	The time it takes during the swing phase of one extremity in a gait cycle
Stance time (s)	The time it takes during the stance phase of one extremity in a gait cycle
Speed (m/s)	Distance covered by the body in a given time
Cadence (steps/min)	Measurement of the number of steps taken per unit time

III. RESULTS

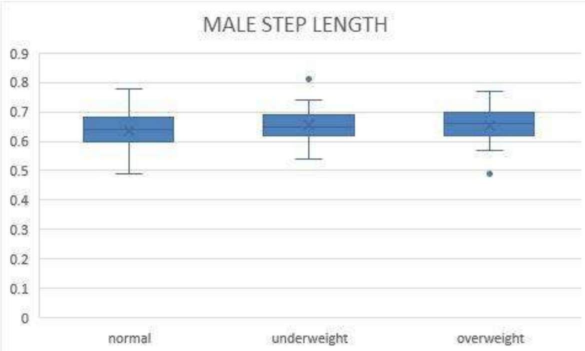

Fig. 1a Male BMI vs. Steplength

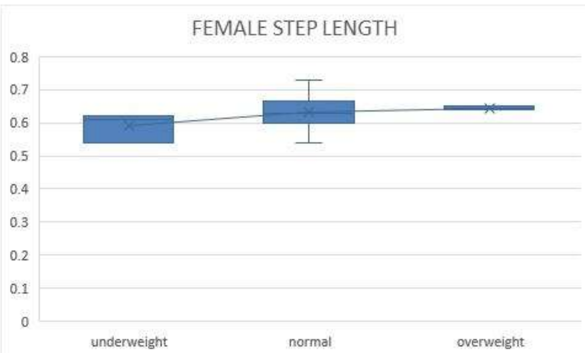

Fig. 1b Female BMI vs. Steplength

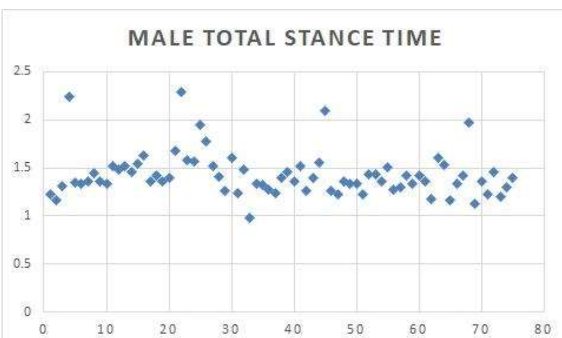

Fig. 2a Plot for Male Stance Time

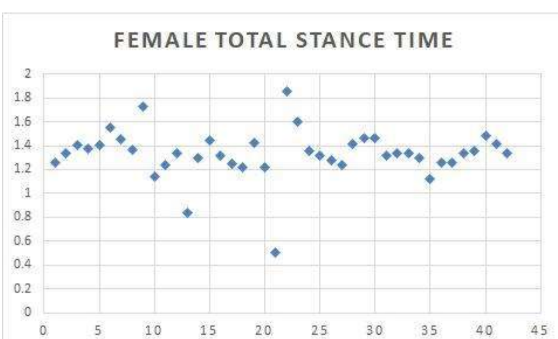

Fig. 2b Female Stace Time

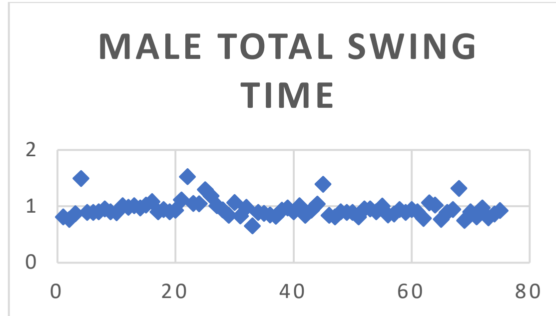

Fig. 2c Male Swing Time

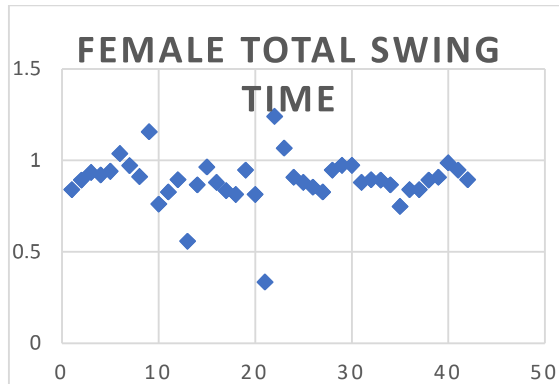

Fig. 2d Female Swing Time

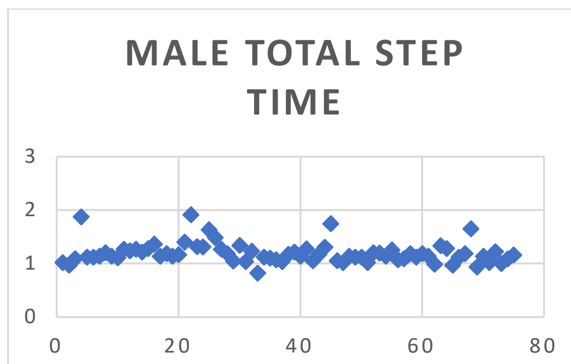

Fig. 2e Male Step Time

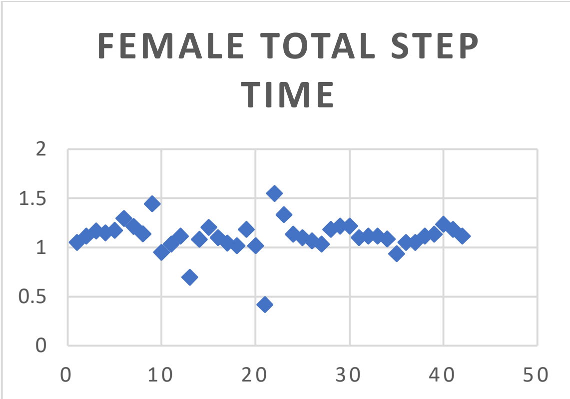

Fig. 2f Female Step Time

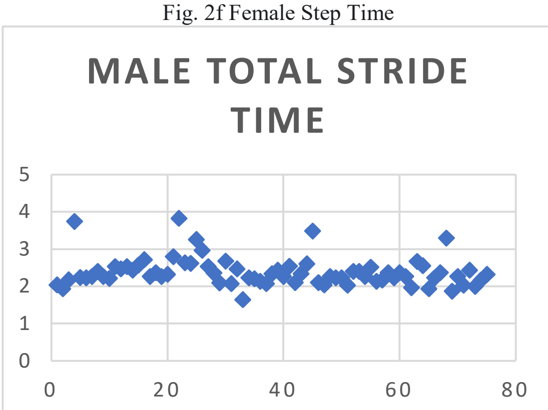

Fig. 2g Male Stride Time

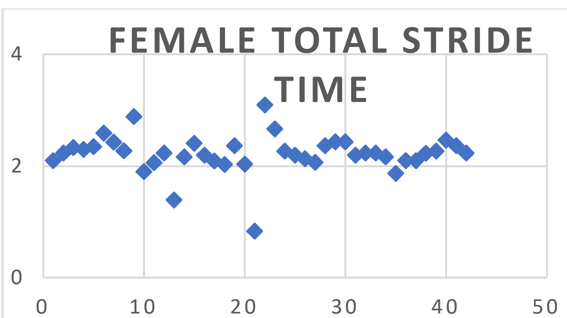

Fig. 2h Female Stride Time

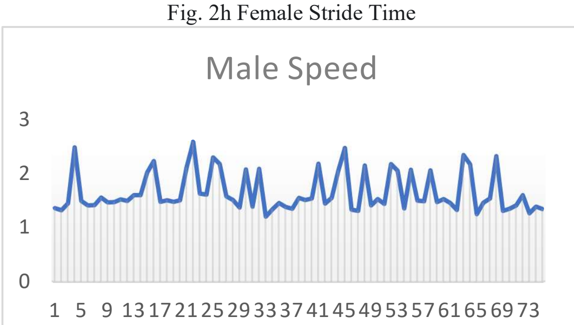

Fig. 2i Male Speed

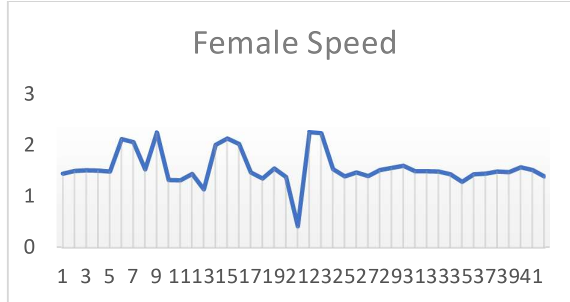

Fig. 2j Female Speed

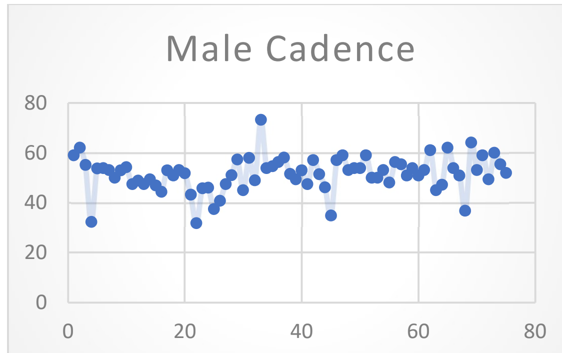

Fig. 2k Male Cadence

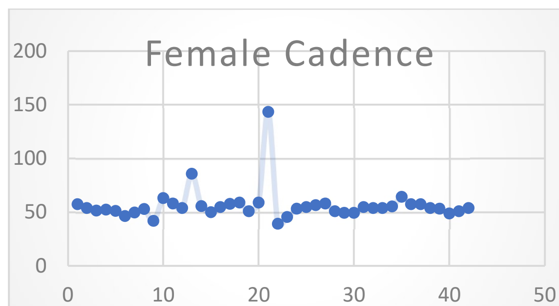

Fig. 2l Female Cadence

	STRIDE TIME (s)	SWING TIME (s)	STANCE TIME (s)	STEP TIME (s)	STEP LENGTH (m)	SPEED (m/s)	CADENCE (steps/ min)
MALE	2.3832	0.9532	1.4299	1.1916	0.6437	1.6558	51.541
FEMALE	2.2228	0.8195	1.3337	1.1114	0.6297	1.554	56.17
% DIFFE RENCE	6.9619%	15.0843%	6.9619%	6.9648%	2.1988%	6.343%	8.5952%

Table 1. Spatiotemporal Parameter % difference for Male and Female

IV. DISCUSSION OF RESULTS

The average of step length when compared to BMI is shown in Fig 1. The result shows minimal difference on both Male and Female in step length. However on average , the Male step length is 2.19% higher than the Female counterpart.

The values for male and female subjects is shown in Fig 2. All of the male spatiotemporal parameters is higher except cadence where Female is 8.59% higher. For the following differences of stride time is 6.96%, Swing time is 15.08%, Stance time is 6.96%, Speed is 6.34%, and lastly Step length is 2.19%.

Overall, there were no significant trends observed when the BMI is considered. The data shows that there is no direct relation between the magnitude of the parameters and the BMI of the test subjects.
This study has several limitations. First, the data came from a relatively small number of subjects drawn from healthy controlled young-adult students from Technological University of the Philippines (ages from 18 to 22 years old). The results cannot be generalized to other age group such as teenager, adult, and elderly people. Further study should involve larger range of age group.

V. CONCLUSION AND FUTURE WORK

In this study, a Kinect v2 was used to perform a gait analysis. The coordinates of the virtual skeleton were utilized to measure the spatiotemporal parameters of the said subjects. The spatiotemporal parameters were compared based on subject's BMI and gender. The results show that some of the spatiotemporal parameters yielded significant difference when the data is compared on gender. On the other hand, it does not show any significant difference when the data was compared based on the subject's BMI.

The future of this research will be a comparative study of Microsoft Kinect V2 and the gold standard, which is the Vicon Motion Capture. The validation will aid future researchers to use a cheaper alternative system which are relatively cheaper yet adequately accurate. Further study should involve a larger number of subjects with a multiple age groups to prove its accuracy.

Lastly, in using the Kinect V2 the effective distance is 3.5m - 4m with the tripod height of 440cm.

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