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BIOMECHANICAL APPLICATION: EXPLOITATION OF KINECT SENSOR FOR GAIT ANALYSIS

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ABSTRACT

Human gait recognition is an important indicator and are extensively studied research area especially with the aging population and rehabilitation applications. Application of gait analysis ranges from diagnosis, monitoring and early detection of potential hazards such as human fall. There are various types of approaches used in gait analysis including wearable, ambient and vision based devices. Microsoft Kinect sensor is well-known among researchers since it can give depth and normal colour images as well. This paper presents a preliminary study on gait analysis of lower body parts. The measurement taken includes step width, step lengths, stride lengths and angles of knee respective hip and ankle while walking. The results showed that the algorithms implemented were able to accurately measure the lengths with low error rate.

Keywords: gait analysis, kinect, lower body, depth sensor.

INTRODUCTION

Human joint measurement and posture recognition is a key area of research in the field of biomedical engineering and rehabilitations applications. There are numerous studies conducted with different sensors for human gait analysis to apply into various situation in the field of rehabilitation and injury prevention. This includes identification of pathological posture and movements, pre- and post-treatment efficacy assessment, early detection of disorders and wellness and safety sports. Various approaches are used to take human joint measurement which includes image based devices, wearable and ambient sensor based devices. Sensors used include accelerometers, gyroscopes, flexible angular sensors, electromagnetic tracking systems and sensing fabrics. However, wearable and ambient or integration of wearable and ambient sensor based devices are not reliable and they used to give false measurement unlike vision based sensors [1, 2] which can accurately identify and classify human movements.

RELATED WORKS

There are plenty of studies carried out on different biomechanical application and review of sensors. This section will only highlight few of such works since this is just a preliminary study. There are significant improvements and enhancements needed for an accurate gait analysis on lower body parts, so that it can be applied in any of biomechanical application reliably.

In [3] presented a real time based gait identification system from Kinect depth stream, which mainly focuses on length of bones and the angles of joints. The system used two features and on this basis they made feature fusion and store feature vector into their own database than used nearest neighbour classifier. The two features are namely as static feature (length of the bones) and dynamic feature (angles of swing legs and arms).

A study by [4] presented a contribution using Kinect for Parkinson’s disease. The data from sensor were used for recognition of gait features and for the detection of disorders in movements. The mathematical approaches proposed were used for motion tracking, gait feature selection and classification and for the study of Parkinson’s disease.

Non-intrusive and accurate gait analysis system was presented by [5] using Kinect sensor to extract gait information. Measurements include standard stride information, arm kinematics and other parameters.
A comparison between pose estimation from Kinect and with other established motion based techniques for pose estimation was presented by [6]. They examined the effectiveness localization of joints and estimation of pose with respect to orientation and occlusion.

In [7] presented a robotic system using Kinect sensor monitoring human gait during normal activities of daily life. They also presented a study of the robot’s accuracy in calculating the parameters required for human fall detection when compared to vicon motion capture system.

In another study, a comparison of motion tracking performance between Kinect sensor and OptiTrack optical system was conducted by [8]. The experimental results from the study concluded that in terms of motion tracking, Kinect sensor was able achieve a competitive performance as of OptiTrack, and also provide “pervasive” accessibility that can enable patients for rehabilitation treatment in clinic or at home.

An evaluation of Kinect sensor for passive human fall risk assessment in home environment was presented by [9]. They evaluated the use Kinect sensor for gathering measurements of temporal and spatial gait parameters with Vicon motion capture system.

In [10] presented an approach for gait recognition based on Kinect sensor for skeleton detection and tracking

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in real time. They evaluated number of body features together with step length and speed, their relevance for person identification.

Another study on measuring of clinically relevant movements in Parkinson's disease patients using Kinect sensor was conducted by [11]. The results showed that Kinect sensor was accurate in measuring the timing and gross spatial characteristics of clinically relevant movements. But, it could not achieve that accuracy in classifying minor movements like hand clasping and toe tapping.

In [12] conducted a study to evaluate the validity and reproducibility of Kinect sensor by using a marker-based stereo photogrammetry system as a reference. The results for reproducibility were statistically similar to results from stereo photogrammetry for four exercises.

MATERIALS AND METHODS

For the analysis of human movements, we use the position of joints and measurement of bone from joint to joint, since these are the parameters that constantly changes and which can distinguish human characters according to anthropometry. This paper will concentrate on the lower body parts because it is more applicable in many rehabilitation applications. For this, the analysis will be conducted on, step width, step length, step time, stride lengths, stride duration, walking speed and step frequency in steps per minute. The sections below will describe on the methods used to calculate the mentioned parameters. Figure-1 illustrates all the foot measurements considered in this paper for gait analysis.

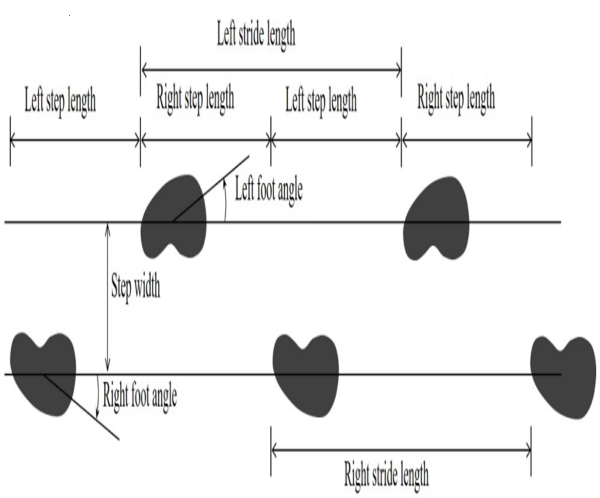

Figure-1. Description of foot measurement.

Step length mentioned here is the horizontal distance along the plane of headway between two alternating steps. For an example, left foot step length is horizontal distance covered during a placement of left step which is from right foot to the new left foot place. Similarly, right foot step length is the horizontal distance covered while making the right foot move forward keeping the left foot at stationery. In other words, this is the horizontal distance along the plane of progression from previous left foot to the newly placed right foot step. The stride length is the horizontal distance along the plane of headway among two successive placements of the same foot. Simply, it is the sum of a right and a left step length. Foot angle depends on how the foot is placed (orientation of the foot) on the floor with respect to the horizontal plane of progression.

For the computation of the parameters, it was assumed that the movements can be either across the sensor, horizontal or vertical to the sensor as shown in Figure-2b-2d respectively. Figure-2a shows the Kinect coordinate system.

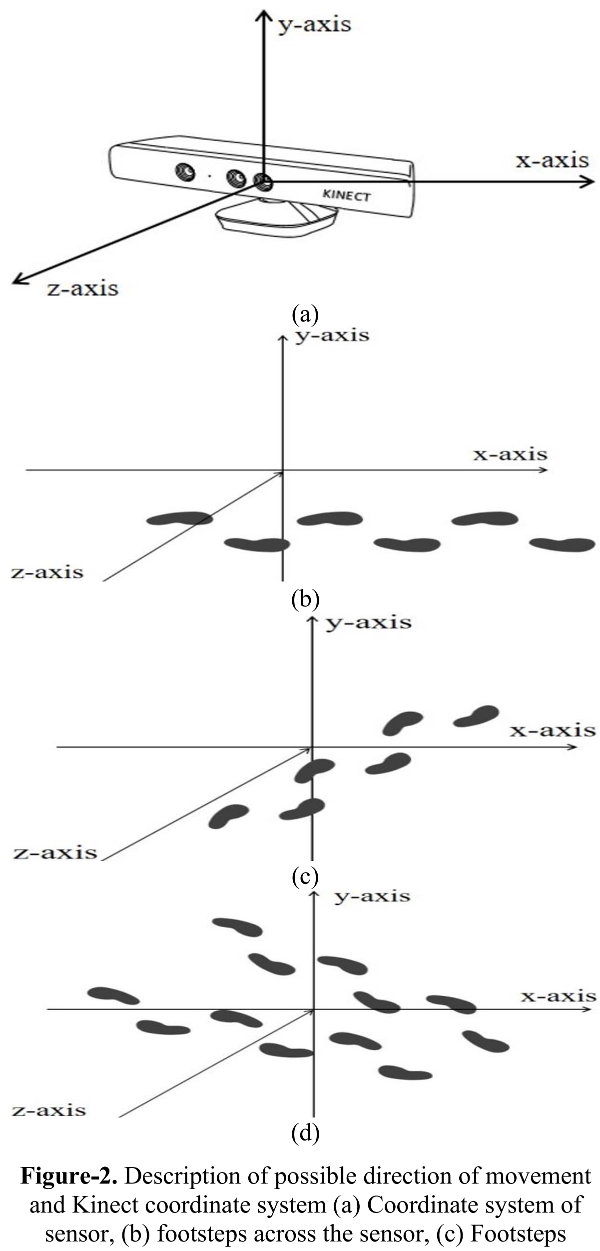

Figure-2. Description of possible direction of movement and Kinect coordinate system (a) Coordinate system of sensor, (b) footsteps across the sensor, (c) Footsteps horizontal (far and close) to sensor and (d) Footsteps vertical to sensor.

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The system will first identify the direction of the movement and then apply the equation accordingly to calculate the parameters needed for the analysis. Direction of the movement is identified by considering the new and earlier x and y values of any foot. For an example, if the difference in between the new and earlier y value of the same footstep is equal to or below 0.05 meters than the movement is considered as across the sensor. Likewise, if the difference in between the recent and earlier x value of the same footstep is equal to or below 0.05 meters, than the movement is considered as horizontal to the sensor (either going far or coming close to the sensor). In case if the above two condition is not true, than the movement will be considered as vertical on to any side of the sensor. Once the direction of the movement is obtained, the equations below will be applied accordingly with the direction as described.

If the direction of the movement is across the sensor, the following equations are used.

Step width = $P\_R_Z - C\_L_Z$ (1)

Left step length = $C\_L_X - P\_R_X$ (2)

Right step length = $C\_R_X - P\_L_X$ (3)

Left Stride length = $C\_L_X - P\_L_X$ (4)

Right Stride length = $C\_R_X - P\_R_X$ (5)

Here, R_z, L_z, L_x and R_x are z value of right foot, z value of left foot, x value of left foot and x value of right foot respectively. The prefix C and P means current frame value and previous frame value respectively. The x and z values in each of the equations above will be interchanged if the direction of the movement is horizontal (going far or coming close) to the sensor. If the direction is vertical to the sensor, than the following equations are applied.

Step width = $\sqrt{\left(R_y - L_y\right)^2 + \left(R_X - L_X\right)^2}$ (6)

Left step length =
$$\sqrt{\left(stepwidth\right)^2 + \left(\sqrt{\left(C\_L_y - P\_R_y\right)^2 + \left(C\_L_X - P\_R_X\right)^2}\right)^2} \quad (7)$$

Right step length =
$$\sqrt{\left(stepwidth\right)^2 + \left(\sqrt{\left(C\_R_X - P\_L_X\right)^2 + \left(C\_R_y - P\_L_y\right)^2}\right)^2} \quad (8)$$

Left stride length =
$$\sqrt{\left(C\_L_X - P\_L_X\right)^2 + \left(C\_L_y - P\_L_y\right)^2} \quad (9)$$

Right stride length =
$$\sqrt{\left(C\_R_X - P\_R_X\right)^2 + \left(C\_R_y - P\_R_y\right)^2} \quad (10)$$

Here R_y, R_x, L_y and L_x are the y coordinates of right foot, x coordinate of right foot, y coordinates of left foot and x coordinate of left foot respectively. The prefix C and P is meant for current frame value and previous frame value.

Right and left stride lengths can also be calculated by adding the immediate left foot step length and right foot step length and right foot step length with the next left foot step length respectively. Other than these, the next important parameters for lower body analysis are speed of walking, knee angles for daily movements, step frequency, step time and stride duration. The angles described in Figure-3 are helpful in determining the step frequency (cadence), step time and stride duration. Since by considering the values of the four angles, the system can decide if a step is placed on floor and whether it is a left or right step. By this way, the system can count the number of steps (number of times right and left foot stepson ground) for a minute to derive the step frequency in steps per minute. To ease burden to the system, counting can also be reduce for 30 seconds for any one feet and then it can be multiplied by 2 for one minute and again by 2 for two feet.

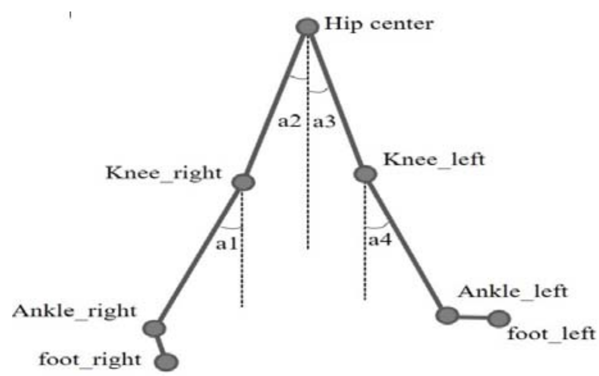

Figure-3. Description of joint positions while making a left step.

By considering the three scenarios, if the movement is across the sensor, the four angles are calculated using the following equations. If the movement is horizontal that is going far or coming close to the sensor or is any vertical movement, than z coordinates values are used instead of the x values in the following Equations. 11 to 14.

$$a1 = \tan^{-1}\left(\frac{R\_k_X - R\_a_X}{R\_k_y - R\_a_y}\right) \quad (11)$$

$$a2 = \tan^{-1}\left(\frac{H_X - R\_k_X}{H_y - R\_k_y}\right) \quad (12)$$

$$a3 = \tan^{-1}\left(\frac{H_X - L\_k_X}{H_y - L\_k_y}\right) \quad (13)$$

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$$a4 = \tan^{-1}\left(\frac{L\_a_X - L\_k_X}{L\_a_y - L\_a_y}\right) \quad (14)$$

Here R_k, R_a, H, L_k and L_a are right knee, right ankle, hip center, left knee and left ankle respectively. The subscript x and y refer to x coordinate value and y coordinate value respectively.

Step time is the time difference between any successive instance of the feet and floor contact of the opposite feet. This is calculated from the same loop used in step frequency calculation, except here the frame difference between two immediate step hit is multiplied by two to state the step time in second. Since the sensor generates 30 frames per second, the number of frames passed between two opposite footsteps can be multiplied by 2 to get the time interval between those frames passed. Similarly, stride duration which is the time difference between successive instance of the foot and floor contact of the same foot can also be calculated. This was calculated in a different loop since stride duration can go beyond one second, but the concept used is the same except that the frame gap between two successive left and right foot is extracted and multiplied by two for left stride and right stride duration respectively. Walking speed is computed by considering the movement of hip center with respective to time. This calculation also takes into account the three possible scenarios that is because the subject may be walking across the sensor, going far or coming close to sensor horizontally or vertically onto any side of the sensor. If the subject is walking across the sensor, than x coordinate is more reasonable to calculate the distance travelled and z coordinate if the subject is going far or coming close to the sensor horizontally. In case for vertical movements, the distance travelled can be calculated using the equation 15. Once distance travelled is calculated, the speed can be computed by dividing it over the time taken.

Distance for vertical movements =

$$\sqrt{\left(hip\_x_C - hip\_x_P\right)^2 + \left(hip\_y_C - hip\_y_P\right)^2} \quad (15)$$

Here, hip_x and hip_y is the x coordinate and y coordinate of hip center respectively. Subscripted, C and P is meant for current frame value and previous frame value.

RESULT AND DISCUSSIONS

Results from preliminary testing showed excellent performance in terms of error rate computed from the actual measurements. To measure the accuracy and robustness of the proposed algorithms, several testing were conducted including walking across, towards, vertically coming close, vertically going far and coming close straightly to the direction of the sensor. Figure-4 shows step width in meters for one sample which is while walking across the sensor. The error rate is calculated by taking the difference of the experimental results and the actual measurements.

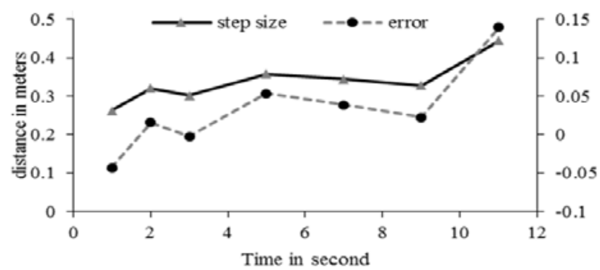

Figure-4. Distance between two opposite legs (step width) with error.

Table-1 shows the actual and predicted number of steps together with accurately detected number of steps. Table-2 illustrates the mean and standard deviation (STD) computed from the average of all samples (across, vertical and around) for left foot stride and right foot stride in meters with actual errors. The actual stride length is approximated to 0.62 meter for the calculation of stride length errors from each frame. The stride length error for both foots showed a lower values for STD than some related work. This means these algorithms can give more reliable results and could be further improved for better performance.

Table-1. Actual and predicted number of steps with accurately detected steps.

	Actual No of steps		Predicted No of steps		Accurately detected steps	
	Left	Right	Left	Right	Left	Right
Across	20	20	20.9	21	4	5
Vertical	40	40	40.2	40.3	7	9
Around	34	34	34.9	34.6	9	4

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Table-2. Mean and STD from average of stride length with respective error.

	Mean	STD
Left foot stride length (m)	1.05	0.92
Left foot stride length error (m)	0.43	0.7
Right foot stride length (m)	0.67	0.88
Right foot stride length error (m)	0.54	0.74

The average of both stride lengths for all the samples is plotted in Figure-5 with respective to the frames. Experimental results for both the stride length measurements showed with a reasonable error rate and with a smaller STD value. Figure-6 shows the walking speed for walking across the sensor for one sample with respective to the time in seconds. The results for walking speed also showed reliable values, even though it was not very accurate for short distance.

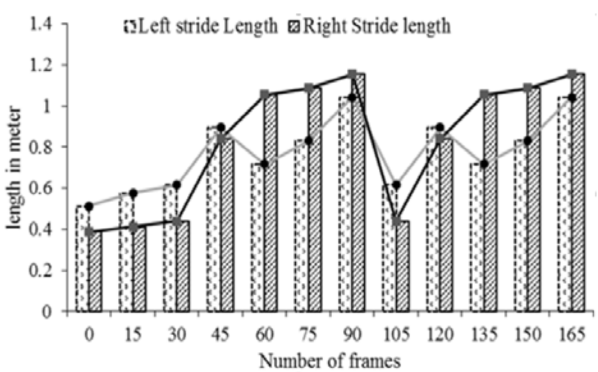

Figure-5. Averages of left and right stride lengths.

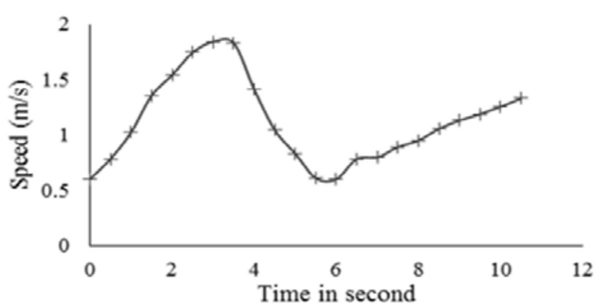

Figure-6. Walking speed in meter per second for one sample.

CONCLUSIONS

This paper is composed from a preliminary study on gait analysis for lower body parts. Exploiting the capabilities of Microsoft Kinect sensor, the proposed algorithms showed good performance in gathering the measurements accurately. The algorithms assumed that the movements can be into three directions. Movement across the sensor, horizontal (going far or coming close) to sensor or vertically onto two sides. With this assumption the parameters are computed from the skeleton data of the Kinect. Even though the result showed reasonable error rate, there are several improvements needed to boost the accuracy. Such as more analysis on the angles in Figure-3 can help to reduce the error rate for step length. Analysis on these angles to gather step duration, stride duration and step frequency are future works.

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