Gait Recognition for Human Identification using Kinect

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ABSTRACT
Gait is a pattern of biometric movement for human identification. Unlike other biometrics such as fingerprint, iris, face, and voice recognition, human gait can be captured with unobtrusive method. In this paper, several measurements are proposed which uses body frame information in 3D space. Body frame data is generated from depth images captured using Kinect camera. The generated body frames are used for human gait analysis. The angle of lower body parts is measured in a gait cycle. In addition, the length of body parts is measured as a feature for combination with the angle measurements. The measurements are compared to each other from 5 subjects who have similar body type. The difference from comparison of the measurements indicates that the human gait has a potential pattern for human identification.

CCS Concepts
• Security and privacy → Intrusion/anomaly detection and malware mitigation; • Information systems → Information systems applications;

Keywords
Kinect; Gait Recognition; Human Identification; Depth Camera; Sensor Device

1. INTRODUCTION
A human gait recognition is one of the traditional biometric methods, like fingerprint, iris, face, and voice recognition [1-4]. Such technologies have been widely used in security fields. However, such biometrics techniques require physiological and behavioral characteristics of different persons for identification. Using the human gait for identification is an unobtrusive technique that means no physical contact is necessary between the subjects and the measurement devices. Identification using the human gait does not require the cooperation or the attention of the subjects. Existing gait recognition approaches mostly use standard video cameras for capturing the movement of walking persons. However, their main challenge is the extraction of characteristic features for identification of the human gait [5-7].

Gait recognition methods are broadly divided into two approaches, Model-based and Model-free. Model-free approaches use binary silhouette information to recognize human gait. Model-based approaches use body information such as body joints for constructing a model. Using a standard camera, capturing body information is influenced by background color and intensity of the light for the gait recognition. Duo to this, these approaches require restricted ambience. With a depth camera, it is possible to capture the depth image which is able to track body information in the 3-dimension without the requirements in the standard camera.

Microsoft Kinect is a depth camera for the Microsoft Xbox gaming console, enabling players to control and play games with their body motion and gestures. The Kinect also enables body detection and tracking of people in real-time by an integrated depth camera using an SDK provided by Microsoft [8]. Color image, depth image, and human body data can be simply extracted from the Kinect device. Accordingly, several researchers already proposed these capabilities of Kinect to analysis for human gait recognition.

We propose some potential measurements such as angle of body joints, walking speed, and length of body to identify walking persons using the Microsoft Kinect with the SDK. Also we expect that some combination of methods can improve accuracy of gait recognition.

Table 1. Specification of Kinect

	Specification
Depth range	Available range 0.5m ~ 4.5m
Depth stream	512 x 424 @30fps
Infrared stream	Enable
Body frame	26 body joints in 3D
Recognizable body	Up to 6 simultaneous bodies

2. BACKGROUND
2.1 Gait Cycle
A gait cycle is the time period of movements known as a stride. The gait cycle is divided into two phases, stance phase and swing phase as shown in Figure 1. Stance phase is that the foot remains in contact with the ground. It occupies 60 percent of the gait cycle with 5 movements. The first movement is heel strike. A heel is the first joint of the foot to touch the ground and the weight is transferred onto the foot. Mid stance involves alignment of body weight on the foot. The heel rises while its toes are still touching the ground. And then, the toe rises into the air. This movement is the beginning of the swing phase of the gait cycle. The swing phase occupies the remaining 40 percent of the gait cycle. It is not in contact with the ground.

Humans have little different gait cycle depending on the individual. We focus to find different patterns based on their gait cycle. According to the test results, angle features from subjects can be compared by the gait cycle.

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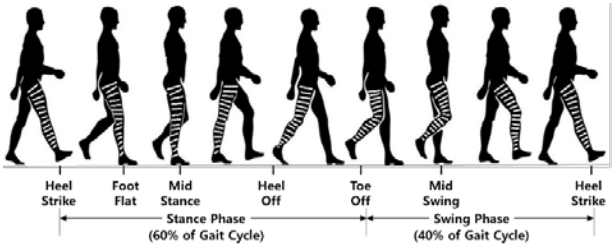

Figure 1. Gait Cycle Phases

2.2 Body Frame with Kinect

We propose a model-based approach for human gait recognition using the Microsoft Kinect 2.0 camera with the SDK provided by Microsoft. The Kinect sensor consists of an RGB camera and an infrared sensor combination for inferring depths. The Kinect device provides body frame data which consists of 25 body joints as shown in Figure 2. Each joint has position in 3D space and an orientation. The body frame data includes 2 finger joints on each hand. Because the finger joints are not necessary for gait recognition, we decided to exclude the finger joints.

Joint No.	Joint Name	Joint No.	Joint Name
1	Spine base	12	Hand-right
2	Spine mid	13	Hip-left
3	Neck	14	Knee-left
4	Head	15	Ankle-left
5	Shoulder left	16	Foot-left
6	Elbow left	17	Hip-right
7	Wrist-left	18	Knee-right
8	Hand-left	19	Ankle-right
9	Shoulder right	20	Foot-right
10	Elbow right	21	Spine-shoulder
11	Wrist right		

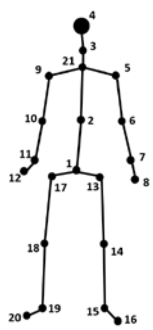

Figure 2. Body Joints List by Kinect

3. HUMAN GAIT ANALYSIS

This section gives a description of the proposed approach, including the processing of the creation of features, and which feature can be measured and have unique differences for the human gait recognition. The parameters for the gait analysis are step length, stride length, speed, angle, progression line, and etc. We decided to use angle of body joints, walking speed, and body length for the gait analysis using the body frame data in 3D space provided from the Kinect device.

3.1 Joint Angle

For the joint angle feature, we propose 3 joint angles of the spine-mid/hip/knee, hip/knee/ankle, and knee/ankle/foot (Shown in Figure 3). Each angle consists of body frame data in 3D space. Most researches for gait recognition proposed distance features [9, 10]. However, the distance feature could have a problem between walking persons who have similar body length and stride. Therefore, we propose the joint angle as the main feature for human gait recognition. The joint angle can be different regardless of the problem.

In order to calculate joint angles in 3D space without wearable sensors and cameras based on RGB color, we use infrared depth data from Kinect device. The joint angle in 3D space is more complicated to be calculated and captured than other measurements for gait recognition. Due to the reason, the joint angle can be more unique than the others.

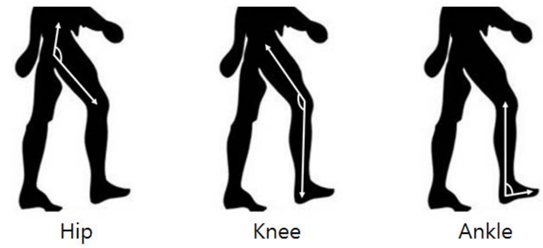

Figure 3. Joint Angles

3.2 Length of Body Parts

Body height is one of the measurements for gait recognition. However, the measurement is weak to find differences between walking persons because human heights are all similar in comparison. Therefore, we propose a measurement, length of body parts between 21 body joints. Assuming that we compare all length of body parts, different persons could have different length of body parts though they could have the same height. This measurement is not suitable for gait recognition. However, with combining this with other measurements, the length of body parts can be effectively used for gait recognition, and improve accuracy of gait recognition.

4. TESTING AND RESULTS

4.1 Collecting Body Frames

For collecting body frames from the Kinect device, we implemented an experiment environment with a single Kinect and a treadmill. All subjects who have a similar body type were tested on the same test environment. They walked on the treadmill operating at 2mph speed in the front of the device, and we collected 2,000 body frames of each subject in 3D data using the Kinect device.

We propose a model-based approach for gait recognition based on the body frames captured by the Kinect device. The Kinect 2.0 device which we used in the experiment can provide XYZ coordinates of the 25 joints of human body at 30 fps. In our system, each body frame contains 21 body joints listed on Figure 2. The collected body frame is measured in meters.

4.2 Extracting Cycles

Due to the variance in an individual's walking speed and length of body parts, the average length of a gait cycle is various from 35 to 45 frames. It is necessary to compute a peak distance of subject's feet for extracting a gait cycle of a walking person. It is an initial point of a gait cycle when a distance of two feet is the farthest. As a forward foot comes back to the front at the end of a cycle, there are three peak distances per cycle. The first peak distance represents an initial point as the heel strike and a cycle proceeds to the third peak distance as the end of the cycle as shown in Figure 4. In the graph, 38 frames from 11^{th} to 49^{th} frame form one cycle extracted by Kinect.

We focused on the body frame data for the amount of frames to calculate features as much as the frames measured in a cycle. For example, in the case of Figure 4, we calculate an angle feature from 11^{th} to 49^{th} frame on its 3 related body joints. By the cycle phases, calculated features can be compared to each other as well.

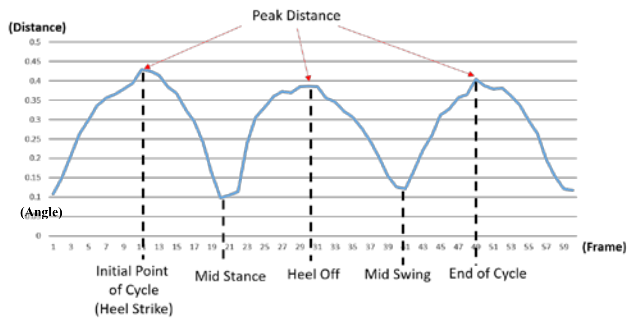

Figure 4. Extracting Cycles by the Foot Distance

4.3 Extracting Measurements

4.3.1 Joint Angles

Since the body frames captured by the Kinect device are 3-dimensional data, a joint angle is calculated using 3-D vectors. Formula (1) is to identify the 3-D vectors. There are three body joints for an angle represented as i, j, and k with x-y-z coordinates. The vector $\bar{a}$ and $\bar{b}$ have initial point j and a terminal point i or k.

$$\text{Vector } \bar{a} = (i_x - j_x, i_y - j_y, i_z - j_z)$$
$$\text{Vector } \bar{b} = (k_x - j_x, k_y - j_y, k_z - j_z) \quad (1)$$

To find the angle θ between two vectors, Formula (2) must be used to find that angle's cosine. $|\bar{a}|$ is the magnitude of vector $\bar{a}$ calculated by Formula (4), and $\bar{a} \cdot \bar{b}$ is the dot product (scalar product) of the two vectors calculated by Formula (3).

$$\cos\theta = \left(\frac{\bar{a} \cdot \bar{b}}{|\bar{a}| \cdot |\bar{b}|}\right) \quad (2)$$

$$Dot\ \bar{a} \cdot \bar{b} = (\bar{a}_x \cdot \bar{b}_x) + (\bar{a}_y \cdot \bar{b}_y) + (\bar{a}_z \cdot \bar{b}_z) \quad (3)$$

$$Magnitude\ |\bar{a}| \cdot |\bar{b}| = \sqrt{\bar{a}_x{}^2 + \bar{a}_y{}^2 + \bar{a}_z{}^2} \cdot \sqrt{\bar{b}_x{}^2 + \bar{b}_y{}^2 + \bar{b}_z{}^2} \quad (4)$$

To find the angle based on the cosine, the arccosine is calculated by Formula (5). A cosθ value is then converted to the angleθ.

$$\text{angle}\theta = \text{arccosine}(cos\theta) \quad (5)$$

4.3.2 Length of Body Parts

The distance between two 3-D points is the length of the path connecting them. In a 3-D plane, the distance between points (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) is given by:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (6)$$

The body frame data from the Kinect device consists of 21 body joints and 4 finger joints. Since the finger joints are used for gesture recognition, we use only 21 body joints for calculating length of body. Each pair of body joints is calculated by Equation (6). Therefore, on referring to Figure 2, the length of body parts are calculated as,

$$\begin{aligned} length\ of\ body\ parts \\ &= d_{(4,3)} + d_{(3,21)} + d_{(9,21)} + d_{(9,10)} + d_{(10,11)} \\ &+ d_{(11,12)} + d_{(5,21)} + d_{(5,6)} + d_{(6,7)} + d_{(7,8)} \\ &+ d_{(21,2)} + d_{(2,1)} + d_{(1,17)} + d_{(17,18)} + d_{(18,19)} \\ &+ d_{(19,20)} + d_{(1,13)} + d_{(13,14)} + d_{(14,15)} + d_{(15,16)} \end{aligned}$$

4.4 Test Results

For the experiment, the proposed measurements are calculated per frame and we compared the measurements by 5 subjects whom have similar height and weight. Even though they have a similar body type, we can find differences in the measurements. In addition, all calculated measurements are compared on a cycle by cycle basis to identify differences about tested subjects. Figure 5 shows the chart which represents variations of left-knee-angles of the subject 1 divided by cycles.

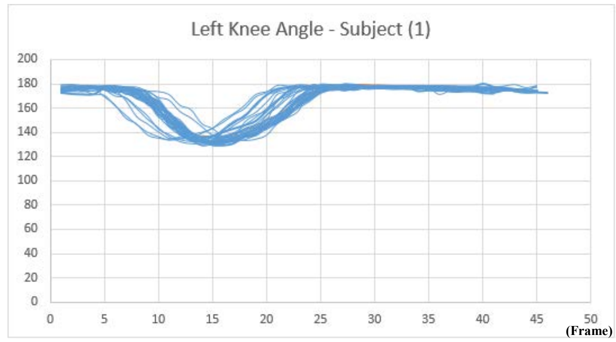

Figure 5. Left-Knee-Angles of Subject 1

Since knees cannot be unfolded forward over 180 degree, the angle of knees mainly stays around 180 degree in a cycle. In the graph, we can know when the subject folds and unfolds their knees. On average, subject 1 begins to fold a knee at the 8th frame and to unfold the knee at the 24th frame in a cycle. So subject 1 mainly folds the knee for 16 frames. In addition, the average frame per cycle of the subject 1 is 42 frames. Figure 6 is a variation graph of angles for the subject 2. The graph represents that subject 2 has a different pattern from that of subject 1. Subject 2 begins to fold a knee at the 3rd frame and to unfold the knee at the 23rd frame on average which means that subject 2 mainly folds the knee for 20 frames. And the average frame per cycle of subject 2 is 43 frames. Therefore, in the difference, subject 2 folds knees earlier than subject 1 does but both subjects unfold their knees around the same time. And subject 2 walks faster than subject 1 does by the duration of the cycle.

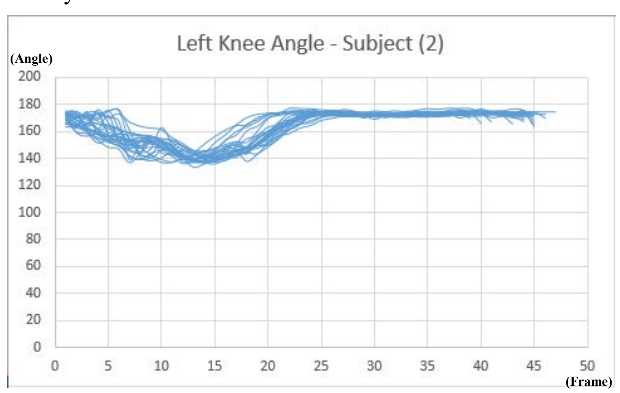

Figure 6. Left-Knee-Angles of Subject 2

Table 2 shows differences of the measurements by the 5 tested subjects who have the similar body type. The highest and lowest angles in a cycle also can be used as a measurement. Each measurement cannot be effective to find a distinct difference for the gait recognition. Therefore, we suggest to compare all of the measurements to expose more differences.

Figure 7 is a graph for left hip angle of subject 1. The patterns of hip angle is little different with the knee angle. Because the forward foot at the beginning of the cycle moves to the back side then comes back to the front side, the angle becomes wide two times per cycle when the foot at the mid stance and the mid swing.

In Figure 7, subject 1's first point of the wide angle mainly peaks at the 14th frame and second point peaks at the 31st frame. In addition, the angle becomes narrow at the heal-off between the two points.

Table 2. Specification of Kinect

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Highest angle	178.91	175.90	178.49	179.18	179.28
Lowest angle	140.68	138.42	134.97	143.22	140.09
Frames per cycle	42	43	38	36	42
Beginning of fold	8	3	1	8	9
Ending of fold	24	23	15	17	21
Folding duration	16	20	14	11	12

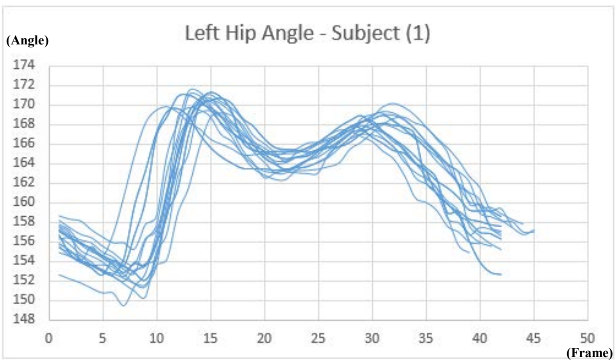

Figure 7. Left-Hip-Angles of Subject 1

Table 3 shows differences of the measurements by the subjects. As shown in the table, we selected the first and second highest angles with its frame when the angle becomes wide, and the lowest angle with its frame when the angle becomes narrow at the middle of the cycle.

Table 3. Differences of Hip Angles by Subjects

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
First highest wide angle & frame	170.54 /14th	168.06 /15th	169.74 /7th	169.88 /13th	169.01 /15th
Second highest wide angle & frame	168.02 /31th	168.36 /32th	166.43 /23th	168.28 /28th	169.22 /31th
Middle lowest narrow angle & frame	164.91 /22th	163.55 /24th	165.17 /15th	162.81 /21th	164.92 /25th

The measurement for ankle angle can be more unique than knee and hip angles because the ankle is the most active part of the human gait. However, even though the variation of angles seem to have a common pattern, the body frame data needs to be perfected due to some outliers from a limited source of data as shown by Figure 8. Therefore, we decided to leave this problem for future work.

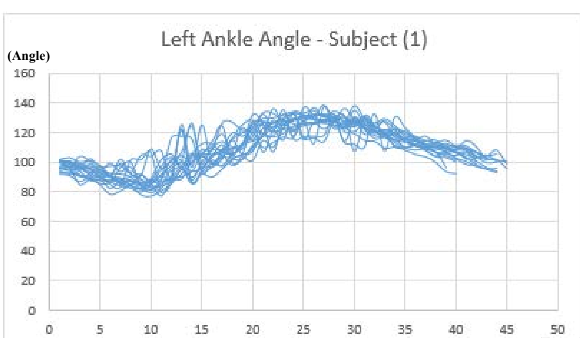

Figure 8. Left-Ankle-Angles of Subject 1

5. CONCLUSION

This paper proposes potential measurements for gait recognition to find a distinct difference based on the human gait. The measurements consist of a body length and an angle of hip/knee/ankle using 21 body frames captured by the Kinect device that provides RGB camera and an infrared sensor combination for inferring depths. Since the Kinect device captures body frames using the infrared sensor, it provides 3-dimensional body frame data without a process of recognizing subjects from background. All of the measurements are calculated by an individual cycle. A group of 5 people who have a similar body type participated in the experiment. As the result of the experiment, we revealed the distinct differences using the angle and body length measurements. However, because we experimented using a single Kinect device which can only capture body frames on single side, mis-capturing of body frames occurs when the body parts overlap each other, and it reduces an accuracy for gait recognition. In future work, we will use multi-Kinect devices to prevent mis-capturing and to increase the accuracy for gait recognition.

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