

## **Gait-based Biometric Identification System using Triangulated Skeletal Models (TSM)**

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### **ABSTRACT**

Human gait identification is a behavioral biometric technology which can be used to monitor human beings without user interaction. Recent researches are more focused on investigating gait as one of the biometric traits. Further, gait recognition aims to analyze and identify human behavioral activities and may be implemented in different scenarios including access control and criminal analysis. However, using various techniques in relation to image processing and obtaining better accuracy are remaining challenges. In last decade, Microsoft has introduced the Kinect sensor as an innovative sensor to provide image characteristics, precisely. Therefore, this article uses a Kinect sensor to extract gait characteristics to be used in individual recognition. A set of Triangulated shape are generated as new feature vector and called Triangulated Skeletal Model (TSM). Nearest Neighbor technique is utilized to do the recognition issue based on leave-one-out strategy. The experimental outcomes indicated that the recommended technique provides significant results and outperforms other comparative similar techniques with accuracy of 93.46%.

**KEYWORDS:** Gait Identification; Kinect Sensor, Nearest Neighbor, Triangulated Skeletal Models, LDA, PCA.

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### **1. Introduction**

Human biometric systems aim to provide an automatic human identification system using behavioral or physiological characteristics [1]. In another vain, various systems have been suggested for human identification based on human features. These systems are aimed to improve the process of identification/verification at banks, airports, border crossings, etc. Furthermore, many biometric trait techniques are used for these systems including voice recognition, fingerprinting, facial recognition, and scanning the retina of the eye. However, such systems need human collaboration and user interaction. Similarly, human gait identification approaches offer a good albeit unconventional approach to human identification since gait is unremarkable biometric traits system. To do so, various devices have been used for the purpose of human gait identification such as Closed-circuit television (CCTV). The CCTVs are frequently utilized cameras for observing and identifying person's behaviors. Currently,

investigators concentrate on using the Kinect camera with the aim of reveal the body-joints of an individual's body accurately. Kinect is a Microsoft product that was originally designed for purpose of gaming device (the X-Box-360). Further, the Microsoft Kinect camera (sensor) has been utilized for various applications like; Sign Language, Robotic Applications, and Scientific Applications.

Kinect sensors allow real-time skeleton-detection and the tracking of human movement based on the use of an integrated depth camera [2]. With the Kinect (camera) sensor (20) joint points can be made regarding the individual's body, it has pushed researchers to focus on Kinect-based gait recognition and classification schemes.

### **2. LITERATURE REVIEW**

Generally, gait characteristics utilized for different purposes by researchers such as: human identification, activity recognition, gender classification, gaming, health care systems, and

human age estimation [3]. Meanwhile, gait identification systems play an important role in various applications, especially in security surveillance systems. Numerous gait-based identification systems are suggested by researchers that categorized into two parts: model-free schemes and model-based schemes [4]. Essentially, model-free schemes work directly on gait sequences whereas an individual's body parts (legs, arms, etc.) are denoted by specific models in model-based schemes [5]. In [6] a model-free gait recognition method is proposed entitled mass vector. In this method a mass vector is generated from binarized silhouettes during one gait cycle. These are based on the pixel numbers with a value of 1 in each row. To test the performance of the mass vector, in this method the problem of matching frame is addressed by using Dynamic Time Warping (DTW) scheme. An alternative gait recognition method investigates step (following and forward) templates to represent gait characteristics [7]. In this approach, Frame Difference History Image generated from static body shapes and dynamic motions. In [8], a Gait Energy Image is generated that represent a single image calculated from the sequence of silhouette frames in one gait cycle. Furthermore, GEI has also been investigated in [9]. This is obtained by dividing GEI into several biomechanical poses made up of four Phases of the Gait Cycle. Contrariwise, model-based schemes mostly deal with a structural model to form individual's gait, aiming to apply the topology of individuals body parts. In [10] stride length and cadence utilized as spatio-temporal parameters to generate gait characteristics and used for individual identification. In [11] a model-based gait identification system is suggested using dynamic features. This is done by creating two different triangular shape; the first is generated from one hand with the toes, while the second is created from one hand with the two heels. Two crossing points will be determined based on the two triangles so formed. The

mean values of the angles and the intersecting points of an individual are then used for the purpose of classification. Moreover, many model-based gait recognition methods have been proposed using the Kinect sensor. The Kinect sensor is a Microsoft product that is mainly used by game controllers. Moreover, it has many applications such as healthcare, retail, education, robotics, and security surveillance systems [12]. a Kinect-based gait identification scheme is suggested in [13] using thirteen static biometric parameters from individual body, whereas in [14], frontal view gait recognition is offered using a Kinect sensor. This method investigates a joint angle data set. The database created by the authors consists of 27 participants and 6 records per participant. The performance of this method is tested using the Nearest Neighbor (NN) method which revealed a score of 79.1% recognition rate. In [15] two feature vectors were investigated to represent individual gait: physical features and dynamic features. Physical features are created from arms and legs, while the dynamic features generated from body motion. Moreover, Support vector machine is used as a classification method. The authors of [16] used 20 participants to create their own database, each participant required to walk ten times. Moreover, the two sets of dynamic features are investigated that represent the vertical and horizontal distances to generate gait signature, followed using NN as a classification method with the Manhattan distance. They used their own database of 20 participants, with 10 records per participant, their proposed method achieved results reach a 92% accuracy rate. In [2] angle and distance features are generated to represent gait characteristics and used for gait identification. distance features deal with human body distance, while angle features deal with some of the angles in human body joints. In their method, Linear Discriminant and NN are utilized as a classification scheme. In another side, different

artificial intelligent algorithms such as convolutional neural networks (CNNs) based on image features are used to provide accurate gait recognition. Further, the experiments via CNN algorithm (to do the gait recognition) provide reliable results in comparison with the traditional machine learning algorithms [17-18]. In [19] a new gait recognition scheme is suggested using Kinect camera, in this method two geometric features generated and called: joint relative cosine dissimilarity and joint relative triangle. In this method, a deep learning neural network is used as a classifier. The main aim of this paper is to offer a high dimensional gait signature called a Triangulated Skeletal Model (TSM) to be used for gait recognition and obtaining better accuracy, yet.

### 3. PROPOSED METHOD

The skeleton-based system was developed in five phases using a Microsoft Kinect sensor (see Fig. 1). The proposed method started by recording the Kinect database as the first phase. The second phase involved detecting/estimating the gait cycle based on a double support period. The third phase was that of feature (signature) extraction. This phase involved creating a set of triangulated shape that generated from the provided joint points obtained by the Kinect sensor. Consequently, during one gait cycle for each frame the angles and the area of the created triangles will be calculated. Mean and standard deviation methods are applied separately on the calculated angles and the area of the created triangles to generate a high dimensional feature vector called Triangulated Skeletal Models (TSM). The fourth phase deals with reducing the dimensions of the TSM, this is by applying PCA and LDA. Both dimension methods are working based on feature transformation methods. At the initial stage PCA method is used to reduce the number of dimensions (i.e. features) of the TSM. This is followed by applying LDA method to do further reduction of the TSM dimensions as well as it is working as an axillary

step for the purpose of classification issue.

Finally, the fifth phase involves the classification mechanism, in this work leave-one-out strategy is utilized to generate train and test set and NN is used as a classifier.

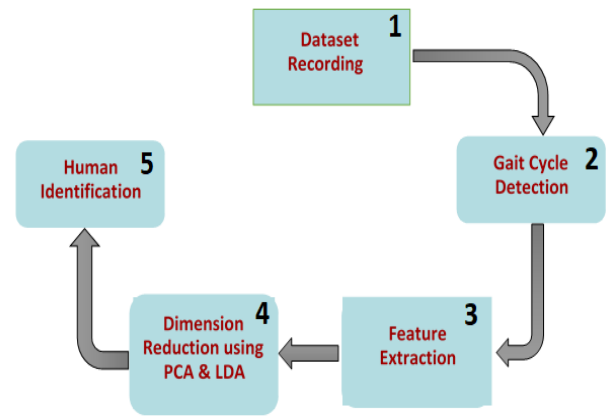
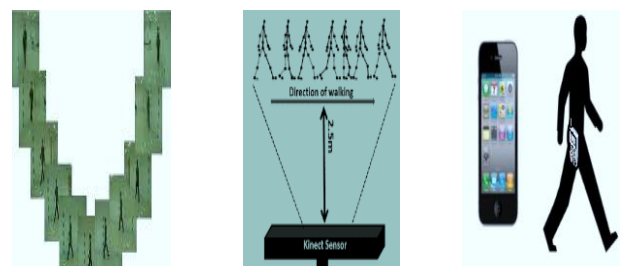


FIG. 1: OVERVIEW OF THE PROPOSED SCHEME

#### 3.1 Database

Various devices have been used to record human gait and activity including onboard traditional camera Kinect sensor and smartphone accelerometer [20] (see Fig. 2). Kinect sensor was originally designed for game applications. Using Kinect for gait-based identification is comparatively new, although [21] provided a free Kinect-based gait database. Nevertheless, skeletal data not provided. Furthermore, there are some researchers focused on proposing gait identification approaches using of skeleton points, however to the best of our reviewing, standard Kinect-database that offers human skeleton points is not provided in the public domain. Mostly researchers have created their own database to address the problem under consideration. Hence, we created a new dataset using Kinect sensor. The dataset originally included 49 candidates that required to walk on a side view of the sensor 5 times. Consequently, the database provides 245 samples as a total.



(a) (b) (c)

FIG 2: HUMAN GAIT DATA A- TRADITIONAL CAMERA B-KINECT SENSOR C- SMARTPHONE ACCELEROMETER

### 3.2 Feature extraction

Feature extraction method aims to extract gait characteristic and normally is started after estimating the gait cycle. In this paper, to detect the gait cycle, we used a double support phase as in [16]. Moreover, unlike extracting gait feature using normal cameras, in this work the features vector extracted based on the provided skeleton information. As explained before, Kinect- sensor offers 20 joint points from the individual body. Hence, the dataset involves X-axis and Y-axis information for each point of human body. From the provided joint points, a set of triangles were generated. When statistical methods (Mean and standard deviation in this work) are applied on the generated values with one git cycle, a new gait signature (feature) was generated that had 9120-dimensional features. These were entitled Triangulated Skeletal Models (TSM).

### 3.3 Triangulated Skeletal Models

In this paper, a Kinect-based gait feature vector was generated using a set of triangulated shape called the Triangulated Skeletal Models (TSM). The TSM is created by three steps; first a set of triangles generated by performing all the probability of forming 3 joint points from the 20 skeletal joints for each frame within a detected gait cycle. Second, calculating the area of the triangle and performing the angles of each triangle (see Fig. 3). The third step involved applying the standard deviation and mean for all triangles area, and the angels during one gait cycle. Now we will provide more details for each step.

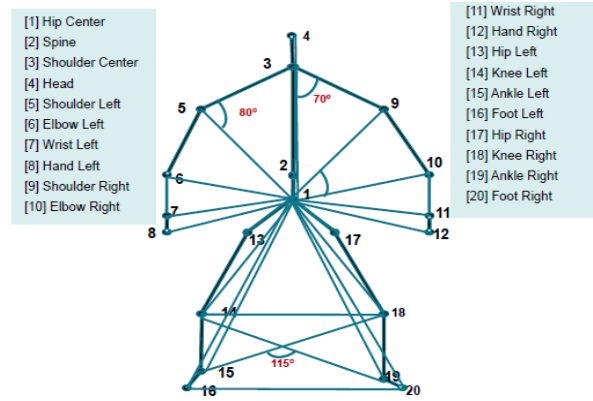


FIG. 3: OVERVIEW OF THE GENERATED TRIANGLE AND ANGELS.

The triangle number is depending on the binomial coefficient. For instance, for the 20 joint points, 1140 estimated triangles will be generated. This phenomenon is named a clique, see equation (1).

$$N_{triangles} = \frac{n!}{(n-k)! * k!} \quad (1)$$

where  $N$  is the triangles number,  $n$  is the joint points number (20 joint points in this work), and  $k$  is the number of points need to form a triangle (is equal to 3). Moreover, once the triangles generated, the three angles and the area of the triangle is calculated using equations (2) and (3), respectively.

$$T_{area} = 0.5 * |\det([x_t; y_t; ons])| \quad (2)$$

where  $T$  represent the triangle area,  $x_t$  and  $y_t$  are the vector coordinate for the 3 provided points.

$$a_1 = \left| \text{acosd} \left( \frac{s_{13}^2 + s_{23}^2 - s_{12}^2}{2 * s_{13} * s_{23}} \right) \right|$$

$$a_2 = \left| \text{acosd} \left( \frac{s_{12}^2 + s_{13}^2 - s_{23}^2}{2 * s_{12} * s_{13}} \right) \right|$$

$$a_3 = \left| \text{acosd} \left( \frac{s_{12}^2 + s_{23}^2 - s_{13}^2}{2 * s_{12} * s_{23}} \right) \right| \quad (3)$$

where  $a_1$ ,  $a_2$  and  $a_3$  are the angles of  $\widehat{213}$ ,  $\widehat{123}$  and  $\widehat{132}$  respectively, whereas  $s_{12}$ ,  $s_{13}$  and  $s_{23}$  denoting the Euclidean distance of the pair joint points, as

presented in equation (4): is

$$s_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (4)$$

where  $i$  and  $j$  representing 2 joint points,  $x$  and  $y$  are the coordinates and  $s_{ij}$  is the computed Euclidean distance for the 2 points. Fig. 4 presents a created triangle based on the previous measurements, while the three joint points selected.

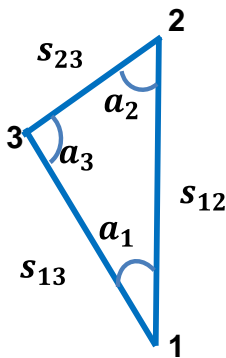


FIG. 4: AN EXAMPLE OF A GENERATED TRIANGLE

Each frame contains a set of triangles and each triangle involves the area with the 3 angles called Triangle Area and Angles (TAA), see equation (5).

$$TAA_j = \{ \{T_{area_{i=1}}^n\}, \{a_{12_{i=1}}^n\}, \{a_{13_{i=1}}^n\}, \{a_{23_{i=1}}^n\} \} \quad (5)$$

where  $n$  is the triangles number,  $j$  represents the index frame and TAA is the triangle area and angles. Hence the TAA includes 1140 generated triangles and each triangle has its areas with 3 angles. Hence, as a total TAA includes 4560 dimensional features for each frame.

Moreover, in gait recognition unlike other biometric system such as face and fingerprint, feature vector will be generated from a sequence of frames in a gait cycle. Since the length of the gait cycle is depends on the person's behavior in walk (i.e. gait cycle frame number is different from one person to another), we need to apply statistical moments to generate feature

vector. In this work we applied mean and standard deviation based on equations 6, and 7 respectively:

$$MeanTSM = \text{mean}\{(TAA_1), (TAA_2), \dots, (TAA_m)\} \quad (6)$$

$$StdTSM = \text{std}\{(TAA_1), (TAA_2), \dots, (TAA_m)\} \quad (7)$$

where  $m$  is the frames number of a detected gait cycle.

$$TSM = \{MeanTSM, StdTSM\} \quad (8)$$

#### 4. EXPERIMENTAL RESULTS AND DISCUSSION

The experiment is based on the skeleton-based Kinect database which involves 49 candidates recorded from angel 90 (side view); each candidate is recorded 5 times. As explained before, the process of feature extraction performed on the detected gait cycle and generate a high dimensional feature vector called TSM. The dimensions of TSM are reduced using PCA and LDA which applied subsequently. In this method NN is applied for the purpose of classification. To divide the samples to create training and testing set, we conducted a leave-one-out cross-validation. In this manner, all the samples have a chance of being used in the testing and training sets. The experimental results are presented in Fig. 5.

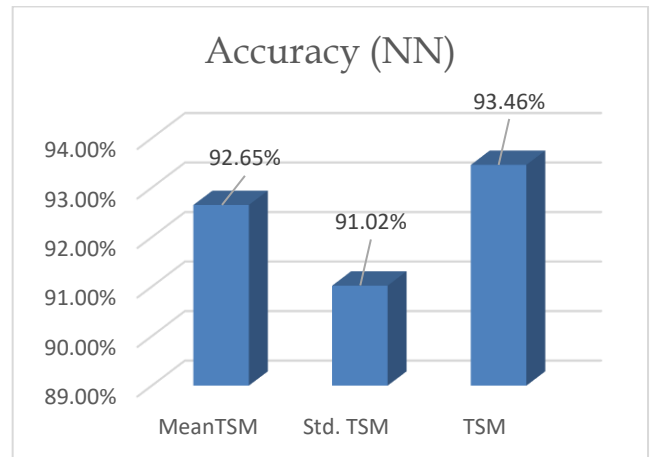


FIG. 5: RECOGNITION ACCURACY OF THE PROPOSED METHOD USING (MEAN TSM, STD TSM AND TSM)

Various TSM schemes are tested in the experiment, includes Mean TSM, Std TSM and combining the two feature vectors based on feature level fusion. The results, as shown in Fig. 4, indicate that the Mean TSM provided 92.65% which is better compared to Std. TSM, which provided 91.02 %, while the combination between them resulted in better performance by providing 93.46%.

Table 1 presents the comparisons between the proposed method with various related approaches suggested in [16] and [2]. The two compared methods are re-implemented based on the same database which is used in this paper. This is because to prove the validity of the proposed approach of this study. The presented results demonstrate that the new proposed approach outperform the two compared method and achieved better accuracy up to 93.46%. This is due to the fact that the new features vector provides more human gait characteristics than the comparative methods including a set of angle and the triangle shapes among all the joint points of human body.

**TABLE 1: COMPARISON WITH OTHER RELATED APPROACHES**

<i>Method</i>	Accuracy
[16]	88.5 %
[2]	86.25%
TSM	93.46%

## 5. CONCLUSIONS

As a result of the literature review, the Kinect sensors camera could be used for gait recognition without users' interaction. Therefore, this study presented a Kinect-based gait identification system. Additionally, a new Kinect database created that contains 49 individuals to test the efficiency of the proposed method. In this database, 5 records are stored for each member. To extract gait characteristics in this method

a new feature vector offered and called TSM. The feature vector (TSM) extracted based on a set of Triangulated shape that carried out from the provided 20 skeletal joint points of the human body skeleton. To extract the gait features statistical moments are applied on the sequence of frames in the detected gait cycle. As a result, three feature vectors generated; Mean TSM, Std. TSM and the combination between them called TSM feature vector. However, the TSM feature vector contains a large number of dimensions. Therefore, PCA and LDA methods are implemented to reduce the dimensions of TSM. NN classifier technique is used to classify human gait. Further, to separate the individual samples into train and test set, the leave-one-out strategy is adopted. The experiments are setup to test the three feature sets. The experiments show that, Mean TSM and the Std TSM provided of 92.65% and 91.02% as an identification rate respectively. In addition, when the combination of Mean TSM and Std TSM is used, the system provides a higher accuracy rate and achieved 93.46%. This is due to the nature of the utilized features of the proposed system since the features provide more information of the gait characteristics. Kinect-based gait-identification under the variation in view angle is our planned future work based on the new dataset.

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