Human Gait State Classification using Artificial Neural Network

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***Abstract*—This paper describes an artificial neural network (ANN) based classification of human gait state. ANN is a well known classifier which is widely applied in many field of applications such as medical, business, computer vision and engineering. This study employs the understanding and knowledge of the human gait analysis. Human gait refers to one's walking pattern. In most cases, gait is used to identify individual due to its unique characteristics. In this work, the most significant gait features is the gait cycle which comprises six states. The six states are classified based on the similarity of the lower limbs' figure and the state of gait is beneficial to real time human tracking and occlusion handling. The state gait classification is performed using an ANN model and presented a performance accuracy of 89%.**

***Keywords* —Gait state, classification, neural network.**

I. Introduction

Biometric is the data which well described individual based on their uniquely physiological and behavioral characteristics [1]. The most common biometric is based on fingerprint, iris and face. However, these are not reasonably practicable for recognition cases at a distance. Recently, gait has become well known as a reliable biometric [14]. Study of gait is increasingly popular nowadays and has attracted many researchers to do research on the method of identification. In general, gait refers to someone's manner of walking. It is unique to each individual and useful in the sense that it is non-invasive and does not require contact with the subject, thus benefiting it to apply in a crime scene.

The variation of human gait style can be used as a biometric identifier to recognize individual and activity. There are many features that can be extracted by observing someone walking. Gait cycle is one of the gait signatures. It is a repetitive pattern involving steps and stride. In this paper, a complete gait cycle is defined as a cycle that consists of six states. Each state represents a pattern of a human walk. By knowing the gait state, the occluded frame can be recovered easily. Furthermore, it is able to improve the quality of people tracking.

Gait state classification has generally been done by many researchers. Despite many existing approaches are available, majority of the researchers [2, 3] use device mounted on the body and extract features by analyzing the data collected by using the device. The work by [4] proposed using an integrated shoes to collect the measurement for gait pattern classification. The wearable device gait pattern classification technique is not practical for use in real time recognition application as the device which is attached on a human body may affect one's walking pattern. The best condition to observe and classify one's gait is without in contact with the subject. Under a noticeable ambient, the target tends to walk unnaturally which is something undesirable for real gait recognition. Hence, the main issue that needs to be considered is the approach for significant feature extraction without using a device.

In [5], a Gaussian mixture model (GMM) based walking pattern classification system was proposed. The GMM classifier produced 90% accuracy. However, the study was not done based on the gait cycle property but instead, it only considered gait patterns that were flat, slope down, slope up, stairs down, and stairs up.

In this work, six gait states are examined based on a complete gait cycle and the gait features are extracted using method presented in [6]. The four main features extracted are the: 1) joint angles between pelvis and ankle, 2) head position, 3) knee positions, and 4) ankle positions. The upper body features such as hand location is not considered as our concern is only on gait. On the contrary, the lower part body features provide significant information in describing gait.

The general framework of the proposed method is indicated in Figure 1. Firstly, image is obtained from the camera. Next, an image pre-processing approach involving background segmentation, dilation, and erosion are performed to enhance the body modeling. Next, a binary silhouette is fitted with its corresponding stick figure model and features are then extracted from that model. To classify human's gait state, the

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ANN technique is applied and K-mean is used to cluster the training dataset into six states. In this paper, the main focus is on the ANN classification technique.

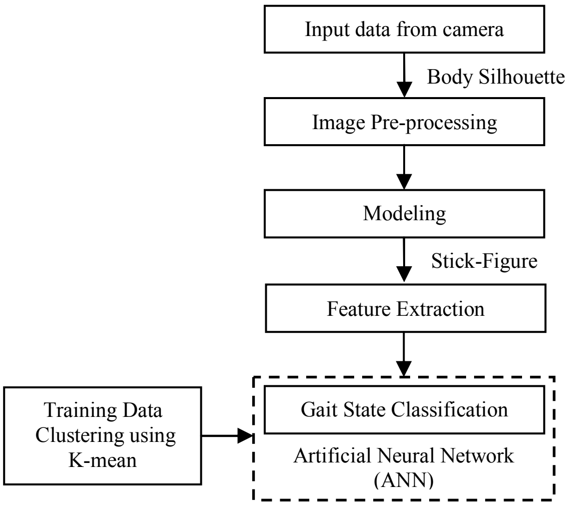

Fig. 1. Framework of the proposed system.

II. Methodology

A. Human Modeling

In general, there are two ways to extract gait features, that is, 1) Non-model based and 2) Model based. The idea of non-model based is to extract the feature from one's appearance such as color and texture. On the other hand, the model based approach (MBA) depends on a prior defined model. Given a new image, a model is fitted to the new image by using a set of objects learned from the pre-defined spaces. Then, the significant features are extracted from the model.

Compared to MBA, the non-MBA is more commonly used as it is simple and its features can be directly extracted from the image itself without involving complicated modeling computation. Nevertheless, this approach has several limitations. For example, when dealing with unstable ambient lighting and different viewing perspective, the non-MBA can cause possible inconsistent classification.

Unlike non-MBA, the MBA can handle the situation better, even when a different subject with similar image features is used. It is because in the latter approach, the features are extracted from the model which is known a priori.

In this work, the MBA was selected and the modeling of the 2D human body follows a procedure discussed in [6]. As this study focuses on gait, only the lower limbs are taken into consideration. The 6 points model is illustrated in Figure 2 and the points involved are head, pelvis, left and right knee, left and right ankle. In addition, Figure 3 depicts the resulting skeleton which was constructed based on the prior labeled anthropometric knowledge.

B. Feature Extraction

A good feature for classification task must be universal, distinctive, and collectable. In here, the gait feature involves the human gait feature, which is a set of information obtained from a person that expresses someone and able to provide strong discrimination. The general concept of gait is the walking pattern. It can be divided into some other features such as cycle time, stride length, joints angles, body height, and variation of angle. Feature selection relies on the application.

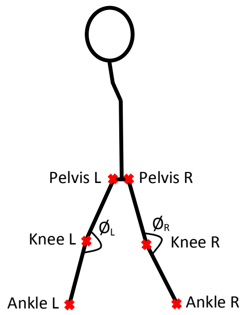

Fig. 2. Skeleton with 6 essential points

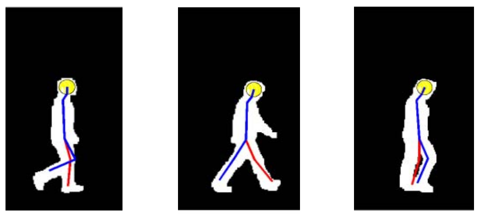

Fig. 3. Resultant skeleton based on work presented in [6]

Ultimately, the main interest is to classify the gait pattern into classes. Six important points can be obtained from the constructed model as mentioned in the previous section.

1. The head (P_H | (X_H,Y_H))
2. Left pelvis and right pelvis (P_{LP} & P_{RP} | (X_{iP},Y_{iP}), i is left or right)
3. Left knee and right knee (P_{LK} & P_{RK} | (X_{iK},Y_{iK}), i is left or right)
4. Left ankle and right ankle (P_{LA} & P_{RA} | (X_{iA},Y_{iA}), i is left or right)

Generally, two types of feature are selected to classify the state of gait: 1) Joint angle 2) Point position. The joint angles, $\emptyset_L$ and $\emptyset_R$ shown in Figure 2 are calculated using the Equation 1, 2 and 3.

$$\cos\emptyset_i = \frac{u_{Xi}.v_{Xi} + u_{Yi}.v_{Yi}}{\sqrt{u_{Xi}{}^2 + u_{Yi}{}^2}.\sqrt{v_{Xi}{}^2 + v_{Yi}{}^2}}\ , i = left\ or\ right \quad (1)$$

$$u_i = (u_{Xi}, u_{Yi}) = (X_{iP} - X_{iA}, Y_{iP} - Y_{iA}) \quad (2)$$

$$v_i = (v_{Xi}, v_{Yi}) = (X_{iK} - X_{iA}, Y_{iK} - Y_{iA}) \quad (3)$$

The head position is defined by the coordinate [X_H,Y_H], where as the position of right and left ankles are represented by point $[X_{rA},Y_{rA}]$ and $[X_{\ell A},Y_{\ell A}]$, respectively and both knee positions are represented by $[X_{rK},Y_{rK}]$ and $[X_{\ell K},Y_{\ell K}]$, respectively. The head position is set as a reference point at the origin with [0,0] coordinate since its position is nearly unchanged. By considering only the points of the knees and ankles will lead to an inaccurate classification since the human gait is dynamic and constantly moves from one location to another. To compute the features, the head point is selected as the reference point [0,0] to serve as the origin for the silhouette.

As the reference point is set, the calculated positions of the knees and ankles are actually described by the vector length of the respective coordinates of the knees and ankles to the origin. Figure 4 represents the X and Y coordinates of both sides of the knees and ankles from the reference point (head).

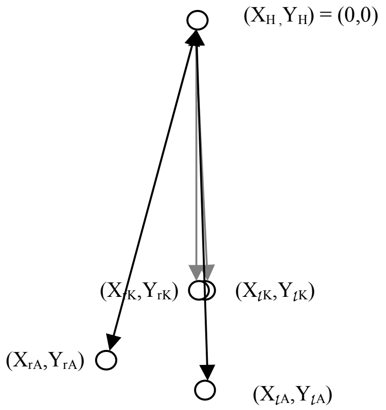

Fig. 4. Position of knees and ankles from the reference point

C. ANN Classifier

The gait state classification general framework is presented in Figure 5. The framework is divided into two parts, namely the Off-line training and On-line testing.

1) Training Data Collection

For training phase, the training data were collected from CMU Motion of Body (MoBo) database [7] involving 5 subjects walking at normal speed are considered. A good training dataset is obtained manually with 6 points corresponding to head, pelvis, knees and ankles.

2) Training Data Clustering

Clustering is a task of categorizing a group of data in such a way that the similar data is grouped in the same class. Clustering is the primary task for recognition and classification. K-means clustering is one of the clustering techniques which widely used due to its fast convergence [8]. It is simple and can be easily implemented in almost any application. However, it is sensitive to the initial condition. For gait features clustering, the initial condition is highly dependent on the study and understanding of the walking cycle. As such, having prior knowledge or a broad observation of the walking cycle can help address the issue of initial condition. In this work, K-means was chosen as the clustering technique and six different classes of gait states were considered.

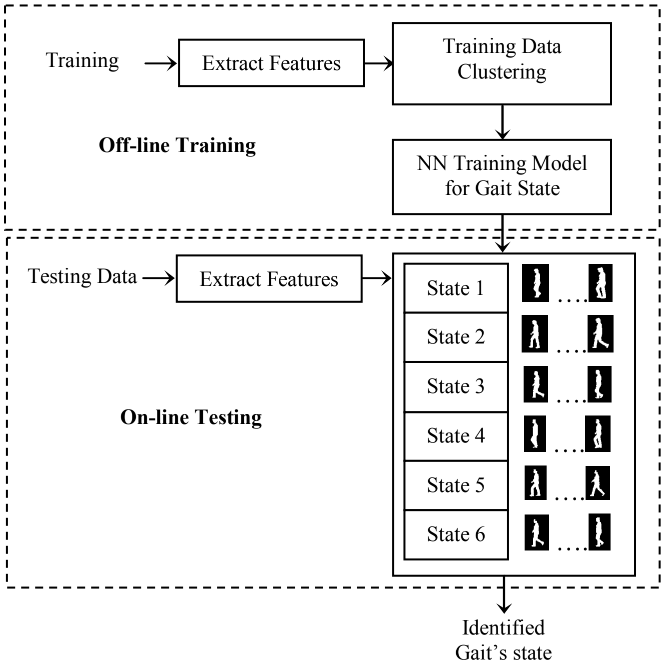

Fig. 5. Block diagram of an ANN based classifier.

3) Artificial Neural Network (ANN) Classification

The main interest of this paper is to classify the gait state using the ANN classification. ANN is a popular classifier [10, 11, 12] at which its performance is determined by a network of neurons and its learning algorithm. ANN classifier provides beneficial aspects to a wide range of applications due to some reasons. Firstly, ANN is a non-linear model which gives a good contribution in real time problems. It is built gradually with systematic procedure to improve the performance criterion following some internal constraints, which is known as the learning rule.

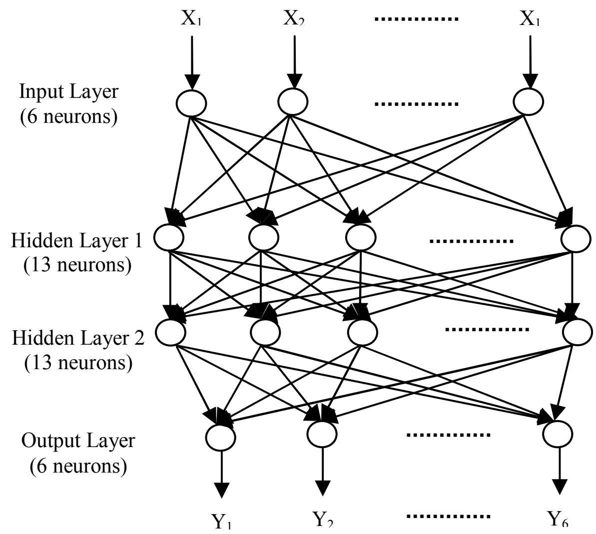

Fig. 6. Neural network model.

As shown in Figure 6 above, the proposed neural classifier model to perform the classification task is a feed-forward, back-propagation multi-layer ANN (FFBPML-ANN) with two hidden layers. The role of FFBPML- ANN is to learn and train a data set consisting of ten inputs [X_1, X_2, X_3,…, X_{10}] and six binary outputs [Y_1, Y_2, Y_3,…, Y_6] which clearly define the six different classes representing the six gait states.

As aforementioned, the angles between the pelvis and an ankles at respective knee points ($Ø_L$, $Ø_R$), the positions of both knees (X_{rK},Y_{rK}) and ($X_{\ell K}$,$Y_{\ell K}$), and the positions of both ankles (X_{rA},Y_{rA}) and ($X_{\ell A}$,$Y_{\ell A}$) are used as input features to be classified by the ANN.

III. Result And Discussion

In this paper, a simple algorithm that employs a neural network model for gait state classification is afforded. The algorithm was implemented in Matlab and tested using the CASIA database [9]. Figure 7 illustrates the result consisting of a sequence of images representing the walking gait of subject 1 walking. It shows a good classification of the gait pattern following the state 1 to state 6 which completely explain a gait sequence.

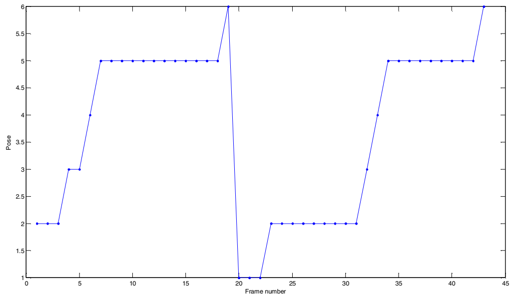

Fig. 7. Plot of classified gait state for a subject

Figure 8 shows a case where the algorithm fails to classify the state 3. In this case, the false classification is due to an inaccurate modeling of the limbs which pose as a major problem that needs further consideration. Knowing the dynamic states of the human gait, real time tracking of human can be enhanced and besides, the gait state can help in estimating the occluded state.

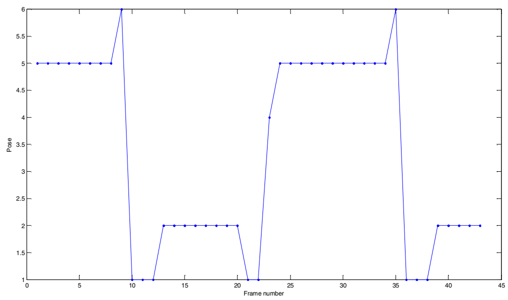

Fig. 8. Failure example.

The proposed approach for classifying gait state is also compared to the method described in [13]. Table I tabulates the classification accuracy of the proposed algorithm and algorithm explained in [13]. Our method is found to have a better classification rate which is 89%.

TABLE I. Table Styles

Method	Features Used	Classification Accuracy
Euclidean Distance [13]	Average silhouette	60%
Artificial Neural Network (Proposed method)	Angles at knee joints and positions from both knee and ankle points	89%

IV. Conclusion

From the study, the results strongly suggested that the FFBPML-ANN classifier can classify gait pattern using the selected six gait features and was able to produce a good result. Additionally, an important point to note is that, to ensure high classification accuracy, accurate limb modeling is vital. Future work will address the development of an improved model and the possibility to involve tracking for real time video application.

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