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HUMAN GAIT RECOGNITION USING BODY MEASURES AND JOINT ANGLES

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ABSTRACT

Gait is the walking style or pattern of the human motions. This research aims to improve the accuracy of human gait recognition using the information provided by Microsoft Kinect. It benefits from a human joint positioning system by Kinect in three dimensions and proposes a new method in recognising the human gait. In this method, the angles between the body's joints during the walking process have been used in addition to the body's limb dimensions and lengths. The result of the experiments has proved that this method can provide higher accuracy in recognising the human gait in comparison to the previous method.

Keywords: ***Human Gait, Gait Recognition, Microsoft Kinect, Biometric, Skeleton Joint.***

1. INTRODUCTION

Gait is the style or pattern of human's walking. It is a unique characteristic of each individual person and is considered as a human biometric. There has long been a common thought that people can be recognised by their walking style (gait) from the front or back. There is a lot of attention to gait recognition in today's researches and in areas such as computer vision, visual surveillance, smart interfaces, and biometrics and access control.

Gait is defined as a cyclic combination of movements that results in human locomotion [1]. It is a repeating sequence of point coordination with an explicit temporal pattern. There is a cycle in a human walking action and the associated joint position coordination which iteratively shows the same set of position change sequences. The uniqueness of the motions for every individual person makes the gait considered as a biometric characteristic. This phenomena is not limited to walking motions and related joint positioning and tracking only but also may extend into the walking speed (from running to jogging) or even in performing some actions such as climbing, sitting down or even when a person tries to pick up or throw an object.

Therefore, gait can be defined as the recognition of some salient property like style of walk, or pathology, based on the coordinated, cyclic motions that result in human locomotion [1]. The available methods to recognise such an identity can be categorised into two major groups which are motion sensor-based and vision-based recognition. Although the detection of joint movements can be measured more accurately by wearable motion sensors, it is more focused on and popular to use vision-based techniques. They promise freedom to the users and are more suitable to be used for security purposes and have more potential to be commercialised.

The unique and popular Microsoft vision-based technique which was introduced in 2010 has been applied to resolve many problems associated with science fields [2]. The Kinect's hardware benefits from a combination of an infrared sensor and source which converts an RGB captured frame into an RGB-D frame. It is capable of detecting a human skeleton and tracking the joint positions. It has been widely used for recognising the human gait by researches such as [3-5], and for increasing the processing speed up to real-time where the accuracy is still high. The estimation of human body joint positions is more accurate in comparison to pure vision-based techniques using RGB cameras only and it would result in a better gait recognition.

'Biometric' is originally a Greek word and means life to measure. Anthropometrics is a field of science studies which takes measurements for

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humans [6]. It includes fingerprints, voice patterns, Iris and hand measurements and as a recent trend, the human gait. These unique characteristics have been used for security purposes mainly because they are unique and always accessible. They cannot simply change, be stolen or hacked.

The advantage of gait over other human biometrics is that it does not need the user's cooperation for monitoring purposes unlike the opposite side with the other biometrics which require a conscious interaction between humans and the computer. This technology would be used in banks, airports or even other public places.
A general view of the gait recognition technique consists of two feature extraction steps and the comparison of the results to the database of gait data [7]. The gait information can be extracted even using very poor capturing quality and resolution for recognition [8] where the results would not change much. This is due to the fact that recognising the gait by nature is in a macro scale and not highly sensitive to the lighting condition when the input device is Kinect, which has an infrared camera as well. There are some other factors that may affect the result of a gait recognition system, varying from footwear, terrain, fatigue or even an injury [1]. According to Figure 1 each feature extraction component receives the raw information from a source and sends it through a matching process. In this stage, the system engine looks for the best match of the extracted features from the input sources with a database of features. The best match would be selected as the person and the related data would be loaded from the database accordingly.

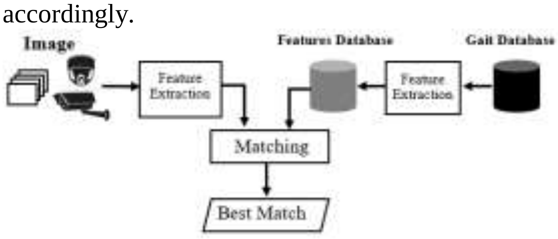

Figure 1- Gait Recognition System General Components

This research aims to find the answer of this question, "How can the information provided by Kinect be used to recognise a human's gait using a different approach which promises an optimised accuracy?"

To answer the question mentioned above, a study has been performed on gait recognition methods and Kinect capabilities and features to support the key-features of gait recognition. A prototype has been developed and an experiment has been conducted to test the idea on a group of participants. This study has been based fully on objective measuring of the accuracy by monitoring the ratio of success and failure by the system administrator during the experiment.

2. LITERATURE REVIEW:

The history of gait recognition goes back to psychologists such as Johanson [9] who showed the ability of humans in recognising the pattern of a moving light in a very short period of time. Recognising the human gait has the same components as any other system. A gait recognition system might have an input coming from a sensor, a process of matching the features and an output which is the best found match. It would be possible to categorise the currently available methods according to each of the system components. There are three groups of methods to recognise the human gait based on the system input mechanism:

A. MV-based gait recognition

The source of raw-data in this type of gait recognition system is a camera. It can either be a recorded video file or a real-time video stream. The advantage of using this technique is the user's freedom caused by no wires being attached to the user's body and recognising the gait whilst the user has a physical distance with the input device. This technique has been widely used in video surveillance systems. The method proposed by Johnson and Bobick [10] could extract some fixed parameters of a human body, such as height, feet distance, pelvis to head distance etc., to recognise the gait. Their approach was based on the human silhouette which is a person in the shape of detected blobs after background extraction. Although the old designed systems for this purpose have been tested on small sample sizes, they have shown promising results [11]. The reliability in recent approaches has been increased by bigger sample sizes. In researches such as [12-14], the accuracy of the recognition has been improved up to 95% by using MV-based techniques.

B. FS-based gait recognition

This type of recognition benefits from a network of sensors which are not directly attached to a user's body to record the joint positions for recognition purposes. These types of sensors sense parameters such as force and pressure. They are able to recognise a person who is walking on a sensor net where the sensors have been fixed on the

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ground. Using such a technique (even in very early attempts such as [15]) scientists could achieve a 93% recognition accuracy rate. The data collection of this method is implicit and unobtrusive. This advantage makes this technique useful for special cases like providing location information in a building. In the real world, these techniques are mostly usable in a building's entrance to perform a security check.

C. WS-Based gait recognition

In this type of recognition, a set of wearable sensors is attached to a user's body to sense the joint positions and acceleration. It is possible to fix the sensors near the human body's joint to track that specific joint to be utilise for authentication. One of the earliest attempts using this technique has been performed by Morris [16]. Three years later Ailisto [17] completed the Morris idea and proposed a model to use such a technique as a biometric authentication system. In his method, four different approaches including absolute distance, correlation, histogram similarity and higher order moments were applied and the recognition rate of 86.3% was achieved. It would be possible to use the mobile phone's implemented sensor for these purposes since almost everybody has one in their pocket.

According to [1], gait recognition methods can also be categorised based on the technique they had used as below:

1) Shape Oscillations: Boyd and Little identified shapes in a captured frame flow in [1] in 2005. They interpreted movements into a series of x and y object coordinations of positions. This system was called shape-of-motion and it was based on the extraction of oscillations from the flow of a captured series of frames. This idea was extended into a shape description over the flow by the same group of researchers.

2) Joint trajectory Patterns: Tanawogsuwan proposed a method [18] in 2001 to use the marker-based recognition technique and measure the angle between human body joints. The combination of hip and knee points on the left and right sides of the body and by comparing the results with the common length got the raw-data for recognition purposes. They achieved up to a 73% accuracy of recognition using this kind of technology.

3) Temporal Patterns in Self-Similarity: The repeating poses and configurations of a human body in a sequence of captured frames within an experiment gave the idea to Ben-Abdelkader [19] to implement a system that used the self-similarity technique to recognise the gait. The sequence of images with a cyclic motion, varied in time, had been used to recognise the self-similarity image and identify the cyclic texture.

4) Pixel Oscillations: Boyd and Jeffery proposed a method [20] in 2001 to recognise the gait from the amount of fluctuation (oscillations) of the pixels in an image and in the sequence of captured frames from a person who was walking. They introduced an array matrix of frequency data which was able to demonstrate and synchronise the internal fluctuation to frequency loops and extract the information of the pixel oscillation phase from that.

5) Other Systems: The other attempts in this area can be categorised into two major groups of Quasi and Non-Recognition systems. The similarity in these types of methods is based on calculations. The level of the optical flow and amplitude of the dimensions are the raw-data for the calculations. They vary in further steps by using a motion-history image, Furrier transformation and motion energy calculation. Ben-Abdelkader et al. published a research [19] which is considered as a good example of applying this technique of recognising a human's gait.

3. METHOD:

The proposed method uses a combination of body limb's lengths and skeleton joint's angles to recognise the gait. An experiment has been performed on a group of 48 participants, randomly, from different ages. They have been categorised in three groups according to their weight and also three groups based on their height. There were 8 persons for each six resulting groups who participated in the experiment. In this experiment, the participants were asked to walk from a certain line on the floor which was located 1 meter away from the Microsoft Kinect and walk towards another line which was 3 meters away. There was a Kinect device installed in front to detect, track and record the participant's gait information in the first round.

The second round of the experiment consisted of choosing the participants randomly and asking them to repeat the same walking procedure. The results of the gait recognition for each participant were recorded by the system administrator by monitoring the walking process and the outcome, to measure the system accuracy. Finally, the results of the accuracy measurement were compared to the results of the other systems and methods to show the contribution of the project.

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A. Calculations

1) Height Calculation

The process of height calculation consists of finding the length of seven body parts as below:

1. Neck: Head to Shoulder Centre
2. Spine: Shoulder centre to Spine
3. Hip: Hip Centre to Spine
4. Right/Left Hip: Right or Left Hip to Centre Hip
5. Right/Left Knee: Knee to Right/Left Hip
6. Right/Left Ankle: Ankle to Right/Left Knee
7. Right/Left Foot: Foot to Right/Left Ankle

There is an extra process to choose either right or left leg for height calculation based on the number of detected joints from the user's hip to his/her foot. The leg with the higher number of tracked joints would be the choice for the height calculation. Therefore, we may summarise the calculation of a user's height using the formula below:

$$Height = \sum_{7}^{i=1} L + D_v \quad \text{(I)}$$

In this formula, D_v is the divergence of the head whilst having vertical movements.

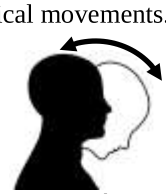

Figure 2 - Head Rotation

2) Hand length Calculation

In order to calculate the hand's length, we planned to do the same as the height by adding the joint distance to each other. In this situation, the hand's length was calculated by adding three values:

From shoulder to elbow
From elbow to wrist
From wrist to hand

3) Leg length Calculation

The calculation of the leg's length consisted of adding three values:

From hip to knee
From knee to ankle
From ankle to foot

4) Hand angle with Spin:

To find the angles between the body limbs and the spine, we created the class Vector3. This class made us able to define 3D vectors. It can also do mathematical calculations and operations, such as vector adding and dot production. Using the named class and the formula below, we were able to calculate the angle between the vectors:

$$Angle = Arccos \frac{Vector.Spin}{|Vector||Spin|} \quad \text{(II)}$$

5) Leg angle with Spine

The calculation of the angle between the legs and the spine is based on two vectors. The first one starts from the spine and ends with the hip centre. The second one is the leg vector which starts from the foot and ends at hip left/right.

B. Recording Process

The engine goes through a five-step process to capture, record and recognise the results of the calculation according to the user's joint position coordination as below:

Step I: Make an invisible interface access to the gait database information for fast access.

Step II: Joint position extraction for three times when the user is 3, 2 and 1 meter away from Kinect.

Step III: Calculation of the average of the results from different distances.

Step IV: Calculate a matrix of the differences between the angles and lengths from the results and gait database.

Step V: Sort the table of the results according to the percentage of the similarity to the gait database information.

4. RESULTS AND DISCUSSION:

Based on an experiment with 48 participants, a database of 28 subjects has been created and a Microsoft Kinect has been used to capture 30 frames in a second and extract the skeleton joint positions out of 2.5D frames. In addition to the 20 joints provided by Kinect, the height and the length of the hands, legs and shoulders were also calculated.

Figure 3 - Extracted Gait Features

All of the participants were asked to walk in a sequence and in front of Kinect from a certain starting point to a particular end line. Each one

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could begin to walk once the previous person had already crossed the end line. As a result, there were 96 walks which included 48 for recording and 48 for recognition purposes. According to the results of monitoring the participants and the recognition results, the accuracy of this method has been calculated as 98.2%, which is higher than recognising the gait according to the previously published researches.

As shown in Table 1, the results of accuracy in using a combination of body angles and lengths could optimise the methods which use length only to recognise the human gait. These examples also used Kinect for recognising the gait for different groups of body parts.

Table 1- Accuracy Rate

Method	Proposed	[21]	[22]	[3]
Recognition Rate	98.2%	97.5%	43.6%	91.0%

It has been shown in Figure 3 that the ratio of accuracy has been raised from an optimised system, such as [21],where the same input tool has been used and a different result has been achieved due to the different methodology in processing the data. In such researches, the Microsoft Kinect data has also been used to capture the depth value of the objects in a frame.

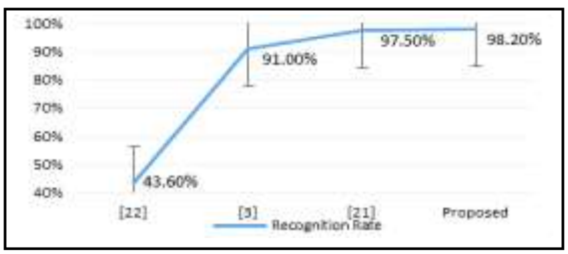

Figure 4 - Proposed System Result Comparison

Another advantage of the proposed method is its high performance in comparison to the other available methods. As mentioned before, this system collects the information in three (3) steps with three different distances. The average of the results in each step is recorded as the gait information considering the changes in their dimensions according the body distance to the camera.

The same strategy has been taken to find the accuracy of gait recognition based on different groups of body limbs in similar researches. The results showed that the combination of the body limb data and the angles between them can significantly change the accuracy ratio. For instance, the ratio of the recognition accuracy of the combination of right and left leg lengths, which was previously recorded at 78.9% [21], has been optimised to 86.3% which shows a 7.4% improvement. It is worth to mention that using these body limbs separately could give 75% accuracy in best case scenarios.

In order to speed up the processing phase and finalise the calculations in real-time, an HMM module has been designed on top of the gait recognition module. This layer tries to sort out the gait database according to the similarity of the gait results. The system generates a temporary copy of the sorted gate database which shows the most similar recognised people in higher levels and calculates the percentage of the similarity. The results proved that in an average of only 7% of the results, the sorting has been changed from the first to the second and third set of results and in the reset, there was a consistent sequence of ordering. The HMM engine helped to define recognition states and reduce the time accordingly. In this module, the system could predict the states of: Recognised, Somehow Recognised and Under Recognition according to the results of the previous recognition. In fact, there would be a backup of every processing history in a separated dataset to use the history for predicting any further actions.

5. CONCLUSION

The ultimate goal of this research was to propose and test a new approach to recognise the human gait. It has studied different methodologies to recognise the human gait. It benefited from Microsoft Kinect as an input device and extracted human joint positions in three dimensions. In an experiment consisting of a designed system and participants, the body limb lengths have been measured. An additional calculation has been made to find the angles between the human hands and legs and spin.

An HMM module has been implemented to predict and sort the gait database. The row with the lowest difference was sorted as the most similar to the results. Thus, the system proceeded with the high ranked similar gait data in the database which was able to speed the computation process up to real-time.

The result of this study will benefit this area to reach a higher accuracy in recognition and faster processing speed. This will be achieved based on providing the similarity of the percentage rather than having an exact result. This technique will optimise the currently available approaches of gait recognition methodologies using RGB-D cameras. This idea will help this industry by providing a lower processing time as it does not track the joint

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positions by extraction of the skeleton from each individual RGB frame.

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