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Gait recognition based on vision systems: A systematic survey

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ABSTRACT

With the growing popularity of biometrics technology in the pattern recognition field, especially identification of human has gained the attention of researchers from both academia and industry. One such type of biometric technique is Gait recognition, which is used to identify a human being based on their walking style. Generally, two types of approaches are adopted by any algorithm designed for gait recognition, namely model based and model free approaches. The key reason behind the popularity of gait recognition is that it can identify a person from a considerable distance while other biometrics has failed to do so. In this paper, the authors have conducted a survey of extant studies on gait recognition in consideration of gait recognition approaches and phases of a gait cycle. Moreover, some aspects like floor sensors, accelerometer based recognition, the influences of environmental factors, which are ignored by exiting surveys, are also covered in our survey study. The information of gait is usually obtained from different parts of silhouettes. This paper also describes different benchmark datasets for gait recognition. This study will provide firsthand knowledge to the researchers working on the gait recognition domain in any real-world field. It has been observed that work done on the gait recognition with sufficiently high accuracy is limited in comparison to research on various other biometric recognition systems and has enough potential for future research.

1. Introduction

The technology of biometric recognition is getting an immense popularity from both academia and industry as it is used to verify the identity of a person using human behavioral characteristics. There are numerous methods of identification out of which some popular ones are iris scan, face recognition, voice recognition, and so on. However, all these methods have one common deficiency that they can only recognize a human being from a short distance margin. But the results obtained by a gait recognition technology shown that it is better than its counterparts while recognizing a human from a considerably long distance. Gait recognition is a process to identify a person using his/her walking style. Different individuals have different gait cycle or walking cycle. It can provide an efficient security infrastructure such as in airports, railway stations shopping malls, and so on [41]. Basically, the gait cycle is a quantification of the time period between two successive hitting by the same foot of an individual. In the case of a normal person, walking happens simultaneously, i.e., it happens smoothly without losing the balance, but this simple walking involves many complex events. Normally, any Gait cycle can be segregated into two separate phases as per research studies conducted by different researchers (Fig. 1). The first phase is the stance phase, which accounts for the period for which the foot of an individual is in contact with the ground from any aspect. In contrast to this, the swing phase accounts for the period for which the leg is in the air, i.e., no contact between the foot and floor. In the swing phase, the moment of leg swing is in the forward direction and this phase starts immediately after the completion of the stance phase.

A stance phase of a person's walking style can be further segregated into five more parts:

- Heel strike: Heel is striking the floor.
- Foot Flat: The posture in which a foot and ground is in complete contact.
- Mid-Stance: It is just the mid of the stance phase.
- Heel Off: It is a component when the heel is leaving the ground.
- Toe Off: It is a component when the toe leaves the ground.

Similarly, to the stance phase, the swing phase is also further

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segregated into three parts:

- Acceleration: A Person tries to accelerate the leg forward.
- Mid-Swing: It is a component for which a leg remains in the center of a swing phase.
- De-acceleration: A person tries to stop the leg for the next heel and prepares for the next stance phase.

The human gait has 24 different components shown by medical and psychological studies, which could be used to identify a person. In the previous work, there are light points and joints attached to an individual, where the light points can be used to differentiate human activities and joints can be used for representing the motion of humans. Generally, two types of approaches are adopted by any algorithm designed for gait recognition, which is discussed as follows:

1. Model based: This approach utilizes the body parts information like joints of an individual to construct a gait recognition model. But the gait sequence required in a model-based approach must be of very high quality [23]. So, to provide a high-quality gait sequences to the system, there must be a presence of a multi-camera setup. Model based algorithms are following: -
   - Jhonson used light bulbs that are attached to an individual and the moment of these light bulbs is tracked in order to capture the walking style of the individuals. Another system used the body outline to create the stick model for the gait recognition.
   - Jhonson proposed a gait recognition algorithm in which he used various static parameters of humans. The static parameters are height and distance between various body points.
2. Model free: This approach uses a binary silhouette for the recognition of the gait of a person. Silhouette is a solid shape and single-colored image of a person or subject. Usually, the color of the Silhouette is black, and the interior is features less. The extraction of silhouette involves the use of background modeling techniques. Some model free algorithms proposed by researchers are as following:
   - Murase and Skai [33] proposed a parametric Eigenspace technique for recognizing the gait of a person. The silhouette image acts as an input in this technique and that image can be further divided into image sequences. Image sequences can forecast on Eigenspace, which can form trajectory Eigenspace. Then the distance between the trajectory and reference trajectory is calculated, which is then further used for the classification of the gait recognition.
   - Chen et al. [8] proposed a scheme by which incompleteness of silhouette can be suppressed based on strong, dynamic gait representation and it helps to formulate a different energy image.

1.1. Gait recognition vs. Other traditional biometric methods

Gait recognition offers many advantages in comparison to other traditional biometric methods. Some of the advantages are as follows:

- In gait recognition, the person can be recognized from a considerable long distance, whereas in biometric methods like fingerprints or retina scan the individual be near a biometric data collector.
- In gait recognition, the individual can be analyzed in low-quality images or low-quality resolutions whereas in biometrics like face recognition requires high-quality resolution.
- The gait of an individual can be recognized in gait recognition using various instruments like cameras, floor sensors, or radar.
- In gait recognition, there is no need for the cooperation of the individual, whereas biometric methods like fingerprint require the full cooperation of an individual.

2. History of gait recognition

The idea of gait analysis was begun by Borelli (1608–1681). He had provided the description of various gait cycles and movement of the muscle motion when an individual can walk. He was the first scientist who had measured the gravity of the body center of an individual. He described when a person walks how the body is balanced through the forward displacement of the center of gravity beyond the supporting area. Gait recognition was firstly used in the field of medical treatment and psychology [34]. Till 1994, Niyogi and Adelson used gait features in the field of human identification. They used Spatio-temporal edge for the surface of the body and silhouette movement of the person. In the U. S the department of defense launched a project Human ID in 2000 and the defense department in cooperation with many colleges and universities to do the work of gait recognition.

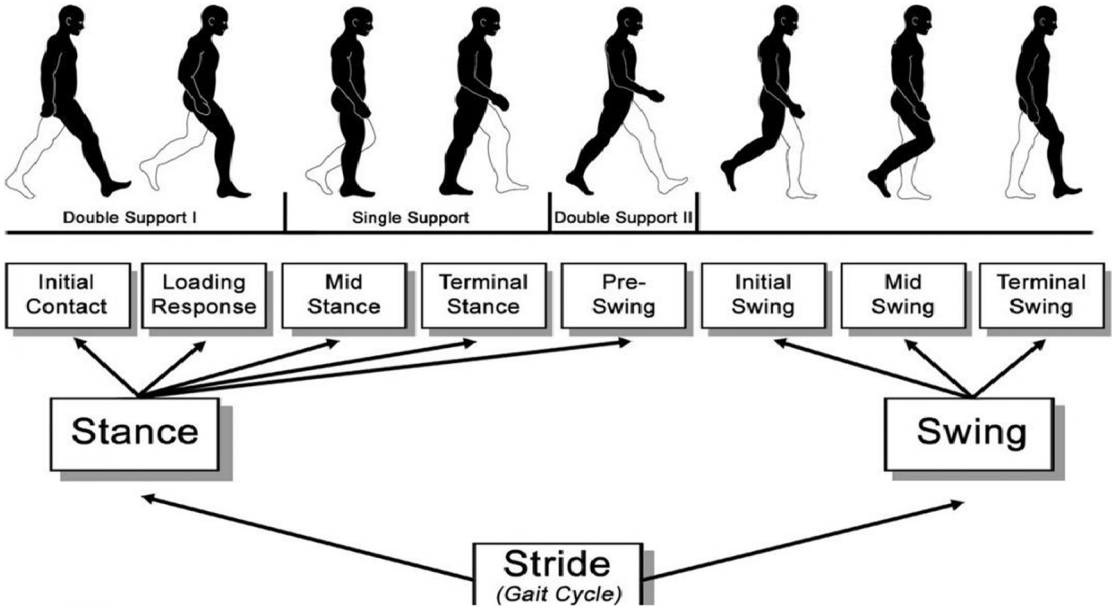

Fig 1. Gait cycle.

2.1. Gait recognition with photographic methods

Willhelm and Eduard Weber have developed a method in which they used serial pictorial images to measure the movement of individuals. Their method is known as chronotography. Mary and Edward Muybridge firstly adapted this method in Paris in 1885 and in California in 1902. They both reveal, capture the normal walking motion speed of the horse by several stationary cameras. The chronotography method was a time-consuming, but useful method for the gait recognition of an individual [49].

2.2. Three-dimension motion analysis

The three-dimensional method of human motion was introduced by Braune and Fischer. The light-emitting markers embedded with trigonometric measurement abilities were used to produce pictures. With the frequency of 26 images per second, the pictures are produced. The three-dimensional technique studies the angular displacement of the lower limb joint.

2.3. Camera based 3-D motion analysis system

The first automatic motion system was developed in 1976 where the television camera and computers were used. This automatic motion system has used 1–16 cameras, a portion of light-emitting diode markers that lay on the anatomical land markers, and a control computer using a data transfer system. The disadvantage of the automatic motion system is that a person must wear a hardwired, which can receive the required power for marker lighting. VICON system can overcome this disadvantage. VICON is an optoelectronic system used for the measurement of motion. It considered 5 television cameras and those cameras are at the distance of a 10 m walk away.

3. Motivation

Over the past 20 years, many surveys have been conducted for gait recognition to cover different aspects, but there are some aspects which are not covered by any of them [48], which are as follows:

- Maximum survey done towards gait recognition considered only the camera-based recognition systems without bothering about other types of gait recognition systems such as floor sensors and accelerometer based.
- The existing survey articles have not covered the influence of environmental factors like frame rate, clothing, multi-view, and walking speed.
- Some popular classification techniques like SVM, Hidden Markov model, etc. were generally discussed by exiting review studies, but none of them had considered neural networks classification.

To overcome these shortcomings of the existing surveys on gait recognition, we present a comparative survey on the gait recognition systems and approaches. The key points of the work presented in this survey are:

- Proper formulation of data acquisition, feature depiction, dimension reduction, and categorization for gait recognition.
- The environmental factors that can influence the performance of the gait recognition system are also considered in our work.

4. Gait pattern analysis and recognition

Gait can be used for different applications ranging from health care, disease diagnostics, age, gender, emotion, etc. Many pattern analysis algorithms are there which require a gait for broadcasting the contrast present in the design of a gait and predict the factors that can influence a specific gait design like patient gait, male or female gait. For example, Barclay in 1978, Furnham in 1997, Troje in 2006, Hadid and Pietikun in 2009 have studied the impact of the gender factor on the gait of a person. Since, the invention of technology to capture the motion of a person, healthy subjects and patient gaits have received the maximum attention from researchers like Thorhill and Moller in 1997, Allel in 2008, and Rosengren in 2009. However, Nigg in 1994 studied the age and gender characteristics of gait, while the changes in age-related gait were researched in 2001. In 2009, walking surface, footwear, and age on gait were researched by Meanant. Tao et al. [46] presented a general tensor discriminant analysis (GTDA) as a preprocessing step for LDA. They developed three different Gabor-function-based image representations called Gabor, Gabor D, Gabor SD and achieved superior performance for gait recognition based on image sequences from the University of South Florida (USF) HumanID database.

Singh et al. [47] presented a survey on the current progress made towards vision-based human gait recognition. Measuring metrics that can be used to measure the performance of the gait recognition model under verification and identification mode was discussed by reviewing the model based and model free studies on gait recognition representations. Occlusion, view variations, and appearance changes in gait recognition were discussed. Maria et al. (2017) presented a novel approach for gait recognition by mobile wearable sensors, and to sketch the most promising techniques, occlusions, illumination, gait intrinsic features Ground slope, shoe heels, and walking speed are all taken into consideration with the datasets available to test many new algorithms.

In the field of gait analysis, one of the most important parts is gait recognition. Since the beginning of gait analysis, it has attracted much attention. Gait recognition includes gender recognition, action recognition, medical recognition, etc. It is related to pattern analysis. Gait is used to analyze and recognize the walker in a group to which they belong.

4.1. Gender recognition

The main aim of gender recognition is to identify a person that is a man or a woman [19]. Koolowski and Cutting in 1997 and Kerrigan in 1998 utilize the face, body, shape, gait pattern for gender recognition. Shan in 2008 and Handid and Pietiknen in 2009, proposed an identification method based on the combination of face and motion. The first experiment for gender recognition was performed with six walkers which had the same height and weight. The gender of a person can be recognized using his walking style from the gait sequences. The human silhouette is extracted from the given gait sequences using the background subtraction technique. The background subtraction used the median value approach. The gender recognition technique has used canonical correlation analysis and SVM (Support Vector Machine). Faster response and higher generalization accuracy were provided by the support vector machine for gender recognition. He performed the experiments on test samples of 786 male and 1,269 females.

4.2. Age recognition

The gait is affected by several features of age, such as step length, speed, and double support time. Researchers have demonstrated that there is a difference between adults and older walking styles [19]. Some researchers analyzed the age by removing the hip center, hip extensions, hip abduction, while some studied the reduced velocity in comparison to the step length with the elderly person group in experiments. The effect of gender and disease in existing studies has analyzed the gait effect of age.

4.3. HealthCare recognition

Study on gait usage for medical applications began in 1990, but practical development started after 2000. At that time 3D motion data

were recorded. The focus of medical recognition is on the dissimilarity between healthy individuals and patients. Many scientists are working on developing the medical application using gait analysis mainly for identifying unhealthy individuals from a group containing both unhealthy and healthy individuals. The results of the analysis are then used to recommend appropriate medical treatment.

4.4. Action recognition

The action recognition based on gait analysis accounts for different actions of individuals like jogging, walking, running, or climbing stairs, etc. The movement technique is observed by extracting functions of human tasks [19]. The various problems are defined by some research categorization of human activities from videos. Action recognition also focused on the walker or pedestrians from image or video. Dedeoglu et al. [13] have described a silhouette-based approach for action recognition, including human walking, boxing, kicking. Dedeoglu et al. [14] have described HMM and SVM-based approaches for action recognition, such as fight detection, in surveillance videos. Petrás et al. [25] have described a test-bed for unusual behavior detection. Ongun et al. [37] have described an HMM-based approach for the recognition of occupational therapy exercises and detection of compensation mistakes for Cerebral Palsy.

5. Applications of gait recognition

The researchers have classified various applications of gait recognition into two categories: the first one is clinical gait analysis, while the second one is scientific gait analysis.

5.1. Clinical gait analysis

Clinical gait analysis notice gait individuality. The key objective of clinical gait analysis is to target and help individual patients directly. The analysis of a gait corresponding to a single person is performed under clinical gait analysis. There are noticeable dissimilarities among the requirements of clinical scientific analysis of the gait. The gait assessment is the prime cornerstone of the clinical gait analysis [50]. In 1983, Rose has described the dissimilarities exiting between gait analysis and gait assessment. According to the authors' study gait analysis is regarded as "data gathering". The easiest type of gait assessment is rehearsed regularly in osteopathic and reintegration clinics. The gait analysis methods are used for the assessment of clinical gait with a character of clinical state. The two possible reasons to make the gait assessment are decision making and documentations.

5.2. Scientific gait analysis

Scientific gait analysis is used as a search tool in the University of Biomechanics laboratory. The main aim of scientific gait analysis is the best conception of gait which can be normal and pathological. It includes the basic study of the walking physiology of a person, how a disease can influence it. The scientific gait analysis can be further categorized into clinical and fundamental research scientific gait analysis. Clinical research involves patients as a basis for research experimentation and study for analysis solutions to various issues. The outcomes produced by the study will help to solve the problems of the other patients in the future. Under a clinical type of research, the study of different diseases and their probable method of treatment are investigated. Fundamental research further aims to enhance our knowledge. The basis of categorization of scientific gait analysis is measurement methods, physiology, human biomechanics, and performance.

5.3. Gait recognition in sport

Biomechanics applications are widely used for gait recognition in the sport. Gait analysis in sport helps people to increase performance. It helps to deal with the risks involved by adopting the walking and running processes. Different types of posture or problems related to movements are identified by analyzing the gait of a person in sports.

5.4. Gait recognition in medicine

Many medical applications depend on the recognition of a gait. The main role of gait recognition in medicine is to deal with pathological anomalous patients to identify walking. Medicine in gait recognition also identifies intramuscular disorders e.g. multiple sclerosis disease in their early stage.

6. Research questions

In order to review the literature research questions are fundamental parts [12]. The research questions that are associated with the gait recognition of an individual are described in Table 1.

7. Framework for gait recognition

The gait recognition system has four phases that are data acquisition, feature representation, dimension reduction, and classification or categorization as depicted in Fig. 2. Gait Recognition result achieved by various authors as presented in Table 2.

7.1. Data acquisition

To accumulate human gait, data is acquired with the help of various data acquisition techniques. Data corresponding to a human gait is basically a set of temporal-spatial data, where human body movements are involved throughout a period. There are many ways to collect the human gait data, but some of the key ones are discussed here like floor sensors, camera, accelerometer, and continuous wave radar[48].

7.1.1. Camera

The walking style of every person has different gait images which can be used to identify the individuals. To capture the videos of the subject, cameras are positioned at some meter distance from the subject. Then the human gait data is recorded in video, which is further used to recognize individuals. Today the most widely used camera is a Microsoft

Table 1
Research questions and answers.

i)	What is gait recognition?	Gait recognition is a technique to identify the persons from their walking style.
ii)	Does it require cooperation of individual?	It does not require the cooperation of an individual while biometric systems like a fingerprint, face recognition, etc. are impossible to be used without the cooperation of an individual.
iii)	Why we use gait recognition?	It can provide security in various fields without requiring the cooperation of individuals.
iv)	What are various approaches used in recognition of a gait?	There are two different approaches to gait recognition, i.e. model-based and model-free.
v)	How many phases of gait recognition are there?	There are two phases, namely, stance and swing phase from which any Gait must be passed in order to get recognized.
vi)	What are the various recordings and processing techniques used to recognize the gait of an individual?	The gait of the individuals has recognized use an accelerometer, floor sensors, camera, and radar.
vii)	Which recording technique is used mostly?	Nowadays, the most used recording technique is the camera.
viii)	Which type of camera is used?	For gait recognition, an RGB-Kinect camera is used.

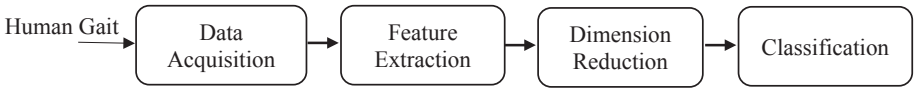

Fig 2. Gait Recognition Overview.

Table 2
Gait Recognition result achieved by various authors.

Authors	Number of Dataset	Feature Extraction Method	Accuracy achieved
Chattopadhyay et al. [6]	30 Frames	Pose Depth Volume and Gait Energy Volume	80.0%
Chattopadhyay et al. [6]	60 Subjects	Hierarchical Approach and LOESS	90.0%
Kumar and Babu [23]	20 Subjects	Trajectory Processing and covariance based	90.0%
Han and Bhanu [18]	122 Sequences /individuals	Statistical approach, GEI, PCA and MDA	80.0%
Makhdoomi et al. [28]	124 Subjects	Averaged Silhouette Algorithm	92.85%
Huang [20]	36 Test sequences	Statistical approach, Spatial and temporal templates	95.0%
Gafurov et al. [16]	300 Gait sequences	Accelerometer Sensor	86.3%
Nowlan [36]	7 People	Accelerometer and Gyroscope	95%
Procházkaetal [40]	51 Individuals	Digital signal processing method and Bayesian	94.1%
Bouchrika and Nixon [3]	440 Samples	Covariate based probe and KNN Classifier	73.4%
Yaacob and Tahir [51]	20 Subjects	Discrete cosine Transform and Principle Component Analysis	80.0%
Middleton et al. [31]	15 Individuals	Floor Sensor Mat	80.0%
Ismail et al. [22]	40 Subjects	Markerless Model Based, ANOVA and MCP	90.0%
Begg and Kamruzzaman [2]	24 Subjects	Support Vector Machine	91.7%
Mazilu et al. [30]	237 Events	Wearable Accelerometer	95.0%

Kinect RGB camera with low cost. The RGB Kinect camera provides 3D skeletal images of 1–2 people. The laser scanner and Kinect camera have the same resolutions. It can work in a variation of 3 m. Li et al. [26] proposed a new plug-and-play method to boost the working of deep models with video data by using the newly sensed and coded temporal information. They exploited the off-the-shelf pre-trained image saliency deep model to obtain high-quality video saliency detection. Ma *et al.* (220) proposed a model for 360° SOD into a multi-stage task to decompose the original complex problem domain into sequential easy sub-problems with only small-scale training data. The goal is to locate salient viewpoints and objects accurately. To reduce the training data shortage problem, a novel dataset called 360-SSOD was created with 1,105 360° omni-directional images whose semantically distribution is more balanced than that of the existing dataset. This method is compared with 13 SOTA methods to check performance superiority. Chen et al. [10] proposed a newly designed depth-transferring strategy followed by building fine-grained, object-level correspondences coupled with a saliency prior to further improve the depth quality of the previous estimation. They feed both the original depth and the newly estimated Depth + into a selective deep fusion network to achieve an optimal complementary balance to make better decisions toward improving saliency boundaries. Chen et al. [9] presented a novel video saliency detection method based on spatial–temporal saliency fusion and low-rank coherency guided saliency diffusion. This study contributed to the fusion of the color saliency based on global motion clues in a batch-wise fashion. The idea of low-rank coherency guided spatial–temporal saliency diffusion is to guarantee the temporal smoothness of saliency maps. Chen et al. [10] proposed a model based on supervised deep convolutional neural networks to improve video saliency detection performance. And planned to find beyond-scope frames with trust-worthy long-term saliency clues and then integrate into the current problem domain for improved video saliency detection. Liu and Sarkar [27] used gait shapes and gait dynamics in their experiment to improve gait recognition by working on the HumanID gait challenge corpus consisting of the largest gait benchmarking data set containing 122 subjects and worked on five different factors such as viewpoint, shoe, time, surface, carrying condition.

7.1.2. Accelerometer

When people walk in a 3-D space, then the accelerations which are used to identify the person are different, accelerometer sensors are placed with the individual's body. Gait recognition using an accelerometer captures the 3-D acceleration of an individual in order to recognize a person [48]. This can include sensors like floor sensors, gyroscopes, etc. This type of system was developed by researchers for collecting 3-D gait acceleration signals from the walking process of an individual.

7.1.3. Floor sensors

The foot pressures of the people are different, which are used to identify an individual. Many sensors of gait system are deployed for the floor to collect human gait data like OR6-7 platforms, sensor mat, load cells, EMFi floor, etc.

7.1.4. Radar

In radar, doppler signatures are generated by various moving components of humans that are arms, legs, torso, etc. The wave radar is positioned at a distance of meters from the subject for the gait recognition system. The continuous-wave radar system is budgeted. It is for automatic door openers using the low power X-band microwave setting module.

7.2. Feature representation

After data acquisition has been done, the next step is feature representation. By combining various data acquisition techniques, it gives result using various feature representation methods such as (Fig. 3):

7.2.1. Model-based feature representation for video data

For human body representation as well as taking out of the features, model-based feature representation is used. The scale and view of the model-based feature representation depend on the video quality. Ben Abdel kader used structural stride parameters of a person for the representation of the human body. There are two parameters, namely, stride length and step, where stride length is measured in meters and steps are measured per minute. These are captured from the gait video to recognize the individual. Model based feature representation technique is a majorly used technique to represent the human body. Boulgouris categorized the human body in various parts and studied the importance of every part that is contributed to gait recognition. The distance and joint angles of the human body used this technique after the human body is modeled.

7.2.2. Model-free feature representation for video data

The objective of depicting a feature using model-free is to procedure the entire movement and shape of the silhouette image of a person. These are two main advantages of the model-free feature representation,

Fig. 3. Gait cycle-based feature representation.

i.e. It is free from video quality which is used to recognize the individual from a distance. Moreover, the computation cost of model-free feature representation is comparatively less than model-based feature representation. Therefore, due above reason's model-free is more popular than the model-based feature representation. Some well-known examples of model-free feature extraction are direct silhouette, gait history image, motion history image, gait energy image, and motion energy image. The silhouette is considered as the key technique of representing the features of video data under model-free representation. In silhouette, it gets pixel of an object and feature representation to convert the image.

For the construction of 2-D grey level images, the mean of silhouette sequences is calculated. Gait history image and gait energy image also convert silhouette into a two-dimensional image like MEI and MHI. Frame Difference Energy Image (FDEI) is the change of the gait energy image. FDEI is mainly used to construct the deficient frame in the sequences by calculating the average value of the cluster.

7.2.3. Feature representation for accelerometer data

The accelerometer has two main methods for feature representation that is gait cycle-based technique and frame-based technique (Fig. 4). Gait cycle-based feature representation has objective gait cycles from inertial signals and after that average cycle, a template is generated from the cycle of classification. The gait cycle-based feature representation has three phases: Phase one is pre-processing, phase two is step detection and phase three is the creation of an average cycle template. Frame-based feature representation can divide the initial signal into multiple frames and every frame is extracted from the feature vector. In the end, the information about the gait is provided by the sequences of feature vectors, which are used to recognize the human gait. It has two phases-phase one is an extraction of the frame feature vector and the second phase is frame feature vectors of the sequences.

7.2.4. Feature representation for floor sensors data

The most common and widely used representation corresponding to the floor sensor is body mass. But it is a weak biometric technique because many individuals have alike body mass, thus the representation rate is low of feature depiction. For example, a criminal body mass is recorded in the database and the information of the body mass of a criminal is used to recognize him. The body mass (M) is computed using the pressure asserted on the floor sensors calculated by utilizing formula $M = KF$, where F represents the pressure readings as measured by floor sensors, while k is just a coefficient.

7.2.5. Feature representation for radar data

Whenever, both the transmitter and receiver are in continuous motion, then both the received and transmitted frequencies are different, this effect is known as Doppler Frequency Shift. The Fourier transform is used to convert radar data which will further help to construct a spectrogram for gait recognition.

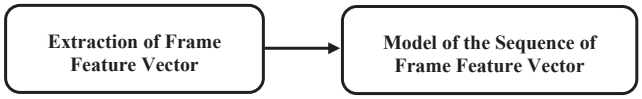

Fig. 4. Frame based feature representation.

7.3. Dimension reduction

The process of excluding the insignificant and poor characteristics from a gait stride and cycles is known as dimension reduction, which is done in two ways i.e. feature reduction and outlier's removal.

7.3.1. Feature reduction

It is one of the most widely used methods for reducing the dimension of the data by removing unimportant, duplicate, or irrelevant features as dimensionally directly influences the efficiency and effectiveness of the analysis. There are many kinds of methods available for feature reduction like Linear Discriminant Analysis, Piecewise Linear Representation, Principal component analysis, Discrete Cosine Transform, I-vector, etc. But among all the most preferable one by the research community is principal component analysis. Every vector is represented as a linear coalition of a minimum number of an eigenvectors and ones that are deviating from the defined rules are filtered out. The comprehensive interpretation of PCA practicing on gait would be established in Cheng's research where he chose k suitable eigenvectors for raising a PCA eigen transformation matrix and then used this matrix for forecast indigenous gait data into k dimensional eigenspace. Discrete cosine transform basically utilizes cosine functions to express the gait signals and it is also a feature reduction method. Linear discriminant analysis is a governing device remembering the various characteristics for the recognition method [48]. It is used to find a vectors pace and helps to perform after mapping data distinguishing process.

$$y = hx$$

7.3.2. Outliers removal

In all machine learning, training algorithms' outlier removal is an integral part. Outliers removal remove substandard class signals. Outlier's exclusion is vital because it will affect the presentation of principal component analysis. Outlier's removal has four types as presented in Fig. 5.

- Outliers in One Frame: Generally, one or some parts of the human body are utilized by some gaits in order to recognize an individual, while the details of other remaining parts captured with gait sequence are treated as outliers.
- Outliers in Dataset: Outliers which are present in capturing dataset refers to an abnormal sequence of gait.
- Outliers in One Gait Video: Usually only a single gait video is utilized by some walking cycles, for example, the dissimilarity of startups stride present in the video with other strides leads to consideration of startup stride as an outlier.
- Outliers Caused by clothes: The change in the normal size of a human as depicted by silhouette resulted due to different clothes wearied by them also leads to their treatment as outliers.

7.4. Classification

The utmost phase of a gait detection system is the classification. It includes Machine Learning, HMM, and Bayesian classification. Distance is the most familiar and linear technique. In this from the gathered data distance is calculated into patterns and stored in the database and a conclusion is made based on the threshold value. The human is dissimilar from their usual expense and it can be treated as outliers.

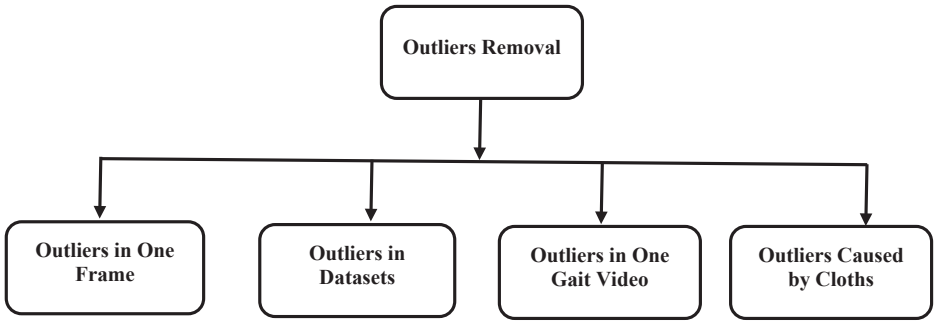

Fig. 5. Outlier removal.

Interconnection is an analytical link to necessitating dependence. Machine learning is the supervised classification of the gait recognition system. Hidden Markov Model (HMM) has many variations. It is widely used for the gait recognition system. Kale proposed the HMM technique to recognize a person by their gait. In this technique, width vectors are used to train the HMM to derive from the series of silhouettes. The parameters of HMM h = (A, B, II) where II was the fledgling possibility and, band A was the observations and transition probability matrices. The Bayesian classification is a rule and it computes the probability that probe vectors match an instance in the database.

8. Data recording and Pre-processing techniques

The data recording and processing techniques are accelerometers, floor-sensors, Camera, and radar.

8.1. Accelerometer

The interval of time present between acceleration values in the resultant acceleration signal is not equal at every point of time. Therefore, the signal is interpolated to produce equal time intervals [18]and after this, the level of fluctuation present in the signal is reduced with the help of moving average filters (Fig. 6).

At the beginning and at the end every gait sample holds some immobile postures [15]. The cause of initiating such immobile parts is not realistic as walking generally starts from a standing posture. Therefore, for the validation mechanism, it is necessary to be capable of differentiating when an individual is walking genuinely [29]. The first step comprises direct original walking parts in the signal. After that cycle is detected and used for recognition. The accelerometer has several unique characteristics that can be either advantages or disadvantages, depending upon the nature of the application:

- Accelerometers are increasingly embedded in cellular phones.
- The smaller size of the device has made it capable to be easily fit in a pocket.

Fig. 6. Accelerometer sensor on the ankle and hip.

- In order to carry out the communication, Bluetooth with a remote station is utilized by the device. The computations are carried out at the remote station.
- The person under study must have to carry the device with him.

8.2. Camera

RGB-D camera is utilized for importing data related to the depth and color of an individual. Microsoft designed Kinect is used to collect depth data with the help of an inbuilt infrared projector and sensors. An erected design of the body surface is created by the infrared laser discharged of Kinect. The infrared camera identifies the element of depth from this network based on the concept of structured light [6]. Kinect consists of a color video camera and has a special arrangement for microphones.

The depth information captured by Kinect is used to detect Gait from the frontal view. RGB-D camera commenced with the growth of function is known as gait energy volume. Over the entire gait cycle, the voxel volumes are averaged together to obtain GEV. But if the captured depth information by Kinect is noisy then it will impact the depth profile which will further impact the performance of GEV [6,7]. Clean profile designs accompanying depth data could be acquired by recording every depth frame and corresponding RGB frame utilizing intrinsic camera parameter.

8.3. Floor sensors

The various constraints are put up in the overall system design. The major dominance of the floor sensor system is that it should be low and expandable. The room in which the acquisition system will be placed has a strained space in which the floor sensor can be placed. A domestic or office environment can have many sensors. Floor sensors have three types:

- Capacitive
- Coax cable is used just as a delay line
- Resistant.

The first approach is capacitors, which can be used as a pressure sensor. The elasticized core is used to make the pressure sensors. It gives the process if deformed the core, separation of the plate is reduced, and enhance the capacitance. These are made on a large-scale using household foil with cling-film just as dielectric. On another side, capacitance grows smoothly and securely while expanding the weight. The various experiments reveal that this technique would not work well on the large scale. If the size of the mat is 16 by 96 then it would require 3076 wires and 1536 capacitors. TDR is mostly used to find the breakage in a transmission line. The individual stands on the coax cable and it would affect the properties of the cable; it looks like a short circuit. This approach is no longer useful because it requires electronics which is complex to handle. The second approach is resisted; it is like a computer

keyboard. In this pair of wires with deformable material is used and made a binary switch. The design of this approach is simple and scalable for the final acquisition system.

8.4. Radar

In a radar system, Doppler Signature is generated for the categorization and to identify the presence of a person when he walks. It includes various moving body components of humans, i.e. arms, legs, etc. The main method used to examine the Doppler signature is Fourier Transform and attributes are identified to recognize the individual. This method provides the security and perimeter protection application with low-cost continuous wave radar as remote sensors. These include detecting intruders approaching a perimeter or at a border crossing. The advantage of this sensor is that this is lesser in cost and there is less power utilization for large area surveillance. The sensor which is lower in cost like acoustic, seismic and passive infrared cause suffering from high false alarm rate (Fig. 7).

9. Feature extraction techniques

The gait signatures of an individual are extracted from the sequence with help of feature extraction methods. There are four methods that are applied to extract the gait signatures.

9.1. I-D radon (RIT-CIT) transformation

To convert the silhouette gait sequences I-D radon transformation feature extraction technique is used. It is converted using the CIT and RIT technique. Making full use of RIT and CIT radon transformation, the appropriate outcome is generated of human shape and movement style [5]. In the motion of the human body, there are different angles of the lower part of the body such as everyone should be different based on the length of their legs, arms, etc. It has been revealed that bio-metric gait recognitions were generally used for user authentication on mobile phones [15]. In his research, sensitive data is captured on mobile phones and work in order to create a strong template for every individual. The author used java for developing the program [18]. From that sensitive data repeating cycle was taken out and the outcome was a single average cycle for every individual. He conducted five steps, namely, time interpolation, filtering, the average cycle length, cycle detection, and average cycle.

9.2. Frequency transformation

The gait cycle of the individual is a periodic pursuit, the Fourier transformation is an interesting technique for time-domain walking signal, where using only some Fourier coefficients to the computation of prejudicial information has been done. [5] used standard image processing approaches to get the gait of individuals from gait sequences have been employed. He focused mainly to get features using the background subtraction technique [5]. The researchers divided the gait analysis technique into a model-based and holistic. These approaches have summarized the dimensionality reduction techniques of the original feature vectors.

9.3. Discrete cosine Transform

In order to perform feature extraction, the shape and dynamic characteristics are examined using Discrete Cosine Transformation (DCT). The main advantage is received using DCT gathered pixel and data which has a similar frequency. After the DCT coefficient is computed, the features are reduced, and to constitute, image quantization is applied. In Fig. 8, DCT is applied on the original average silhouette.

9.4. Feature extraction using Krawtchouk moments

In this, the results obtained by orthogonal set are dependent on the discrete classical weights of Krawtchouk polynomials [21]. The orthogonality moment at present makes sure that there should be a minimum amount of duplication in the data. In most of the cases, the local features of an image are captured using Krawtchouk transformation, where N and M parameters are varied for capturing local features. The silhouette image is captured by the N parameter from horizontal axes, whereas the M parameter is used to capture the image from vertical axes.

Fig. 8. Left-Original Average Silhouette, Right-Reconstructing Silhouette using DCT.

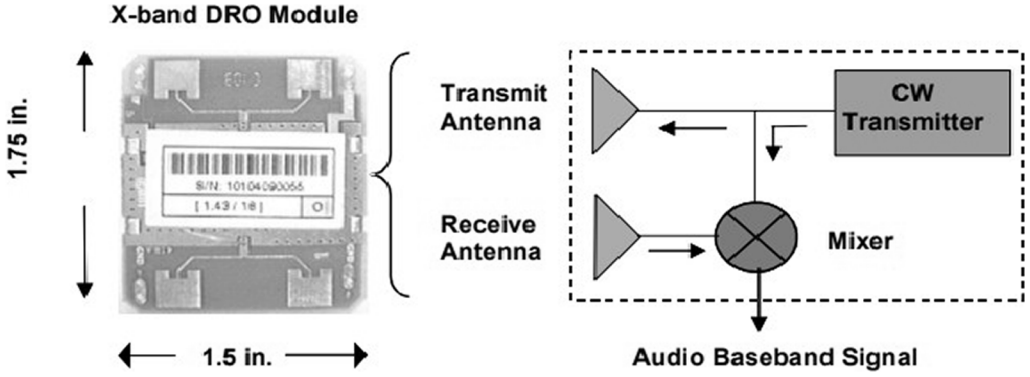

Fig. 7. Radar Moduleloor Sensor Mat.

10. Feature selection techniques

10.1. Statistical method

The first technique for feature selection is a statistical technique taken out from gait sequences. This approach has two gait signatures, the first set of gait signatures is mean and SD, while the second one calculates the gait signature with the combination of mean, SD, and min–max of gait characteristics. The first set makes use of a random walking cycle, which corresponds to vase gait and the average walking cycle corresponds to a support gait in order to compare the identification results. In research, the identification experiment was repeated 256 times. The accuracy of identifying persons is above 95 percent, 3 percent are wrongly recognized, 2 percent are not recognized. In the average walking cycle, the average gait of the testing subject is found. In this subject, data samples are also used and reorganization was organized for times and the rate of accuracy was 99.558 percent. Based on the second set of features, the mean, SD, and max–min were extracted using the coefficient of PC's as gait signature and Fourier coefficients as gait feature.

10.2. Principal component analysis

PCA is a type of linear feature extraction technique and the most widely adopted technique by numerous pattern recognition systems. It has the ability to effectively represent a data point. Basically, data points are projected on the principal axis for the purpose of dimensionality reduction. The principal component analysis is a functional approach for data depiction, data reduction, and data analysis. Gait silhouettes of each image sequence are extracted by Wang in order to apply PCA based eigenspace transformations. The key aim of PCA is to represent data points originally present in an upper dimensional computation space to a lower-dimensional eigenspace in order to obtain various principal components. But, the PCA has a disadvantage too, that it is a multivariate statistical method. But this method of PCA is being sensitized to outliers, lost information, and has a low linear correlation between the participating variables. Data transformation has a huge impact on PCA. So whenever, this type of situation is encountered, apply fuzzy statistics on PCA by utilizing fuzzy sets in the decision analysis stage. PCA is mainly used as a dimension reduction technique as presented in Fig. 9. There are six types of features for classification as depicted in Table 3.

10.3. Classification techniques

The last phase of gait recognition is a classification. Lee applied gait average appearance features for gender classification task. He calculated the p-value of ANOVA, which was used to categorize or order 57 features of various persons [24]. In this order of each feature among 57 features is based on the p-value of ANOVA and used to separate the genders so that the best 6 features are obtained as resultant. The classification phase has various techniques such as distance method, correlation method, machine learning method, Hidden Markov model, Bayesian classification method [28].

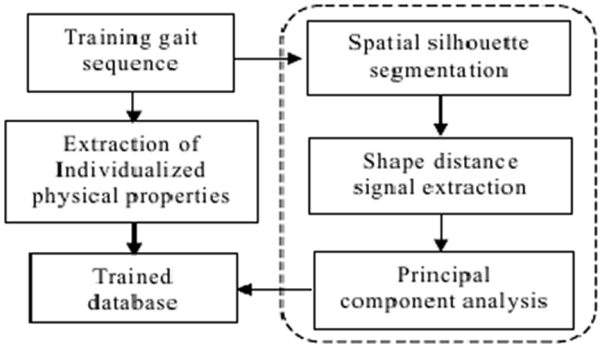

Fig. 9. Gait recognition using PCA.

Table 3
Classification of Six Features Type.

Order	Region	Feature Type
1	hip/back thigh	std of orientation
2	back foot/calf	std of orientation
3	front foot/calf	std of orientation
4	back foot/calf	mean aspect ration
5	hips/back thigh	mean orientation
6	chest/front arm	std of × centroid

10.4. Hidden Markov model

HMM has been used to characterize an individual gait and thereafter recognizing an individual from his gait. HMM has been used in speed modeling and provides a good tutorial on HMM [45]. HMM has been used to recognize human action. As a replacement for the GRF pattern HMM method used authentic GRF value. It is known as the value-based gait recognition technique. The HMM has six gait phases which contemplated as hidden states and the phases conclude with the observation of GRF measured by smart shoes [1]. The hidden Markov Model has been successfully adopted by many applications like speech and hand gesture recognition. The hidden states represent the different phases of gait. In HMM, only the previous state can influence the current state without any impact of the historical state on the current state. Sundaresan et al. [45] have constructed a common framework using HMM for gait recognition of an individual. The position of the subject is considered as the state of the HMM and used binary silhouette feature vectors to instruct the HMM parameter.

10.5. Support vector Machine

Support Vector Machine (SVM) was described by Vapnik in 1995. It is relatively a new technique for classification and regression tasks [2]. SVM is an approximation structural risk minimization technique used in order to reduce the probability of a generalization error. This technique of machine learning is robotized settings of decision. The variations are related to the threshold and set of training data where decisions are prime for the boundaries. When enough data is available, machine learning will outperform manual thresholding [39]. Some successful application of machine learning to accelerate data are particularly abundant in the field of activity recognition, where activities such as running, walking or opening a door were detected with features computed from motion data.

10.6. Distance

Distance is the most ordinary and simple method of classification. In this technique, the distance of gait is collected into a pattern and stored in the database and calculated where the decision is based on the present threshold value [48]. In gait biometric, the Euclidean distance is the most popular metric, which is calculated as: -

$$D(A,B) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$

where the Euclidean distance is represented by $D(A,B)$ between testing data $A = (x_1, x_2, \cdots x_n)$ and the center of each element of the training class $B = (y_1, y_2, \cdots y_n)$. In the final step of decision making, distance can also be concatenated with various other methods of classification. The second type of distance is Manhattan Distance, which is calculated as:

$$D(A,B) = \sum_{i=1}^{n} |x_i - y_i|$$

where $D(A,B)$ represent Manhattan Distance from testing data $A = (x_1, x_2, \cdots x_n)$ to center of each training class $B = (y_1, y_2, \cdots y_n)$.

10.7. Bayesian classification

This concept of probability theory acts as a basis of a Bayesian classification, where Baye's Decision theory is considered as a fundamental approach to the classification problem [53]. The major objective of the decision-making process is to select highly probable and lowest risk option. The Bayesian rule is used to determine the possibility that a probe vector correlates an instance in the database. The rules formulated for the problem solution is described as:

$$P(l|v) = \frac{P(l|v)P(l)}{P_v}$$

where the probe vector is denoted by v and lists the instances in the database.

10.8. Public datasets

The various public datasets are available for gait recognition as presented in Table 4. In any design detection, observe the database utilized for assessment will disclose the latency of detection. The key regards involve distinctiveness and viability, which are generally disclosed by the count of subject instances present in the dataset and the imaging state [35]. If the key motive of the dataset is to check the basic functionality, then data could be obtained from a laboratory scenario; if the major purpose is to show that it could be obtained from shooting subject outdoor. Databases seek to comprise ample subjects to permit for inter- and intra-subject distinctions. Mark S. Nixon used the UMD database that is outdoor data, imitating a surveillance scenario. The National Institute of Standards and technology/South Florida (USF) is a static outdoor data. Southampton and Chromakey combined outdoor and indoor ground [52].

The other public datasets are GeorgiaTech Dataset, UMDHID Dataset, Soton Small Dataset, Soton Large Dataset, USF HumanID Dataset, Oaska Tread-mill (A), Oaska Treadmill (B), Oaska Treadmill (C), Oaska Treadmill (D), CASIA (B) Dataset, CASIA (C) Dataset, and WVU Outdoor SWIRGait. Using the CMU MoBo database silhouette is viewed from six different viewpoints. Whenever one must make a selection from either width or height signals then the signal with correspondingly higher amplitude must be the selection choice [11]. In 2011, the CMU MoBo database has been used by Sivapalan for simulation of GEV's frontal depth in order to synthesize appropriate volume recognition [43]. In his research, 25 subjects are present in the database under four different test classes which are simultaneously captured by using six cameras whenever an indoor treadmill was used by a subject for walking purposes. The classes considered by the researchers are slow to walk, fast walk, walking when carrying a ball, and inclined surface walking.

Table 4
Datasets.

Dataset	Environment	Spectrum	Covariates
CMU MoBo Dataset	Static Indoor	RGB	Viewpoint, Pace, Object
Georgia Tech Dataset	Static Indoor, Static Outdoor	RGB	Pace
UMD HID Dataset	Static Outdoor	RGB	Viewpoint
Soton Small Dataset	Static Indoor	RGB	Shoe,clothing, object
Soton Large Dataset	Static Indoor, Static Outdoor	RGB	Viewpoint,time
USF HumanID Dataset	Static Outdoor	RGB	Viewpoint, shoe, surface
Oaska Treadmill (A)	Static Indoor	RGB	Pace
Oaska Treadmill (B)	Static Indoor	RGB	clothing
Oaska Treadmill (C)	Static Indoor	RGB	Viewpoint
Oaska Treadmill (D)	Static Indoor	RGB	Gait Fluctuation

10.9. Vulnerabilities in gait recognition

Every individual has a different gait just like fingerprints. One of the important applications of gait recognition is that it is used to identify a person from a considerable distance, whereas other biometric required a person to the reader and scanner machine. Whenever gait is used as a recognition system, it has plenty of advantages in comparison to traditional forms of biometric recognition approaches. Some of the factors which make it better are unobtrusiveness, space detection, decreased detail, and it is very onerous to hide [38]. However, there are also some factors that can affect the gait of an individual like walking behavior changed under drunken or inebriated state, pregnancy, accident, weight loss or gain, etc. Moreover, the clothing of a person can also impact gait signatures. Biometric system also has vulnerabilities as it can also be misguided by using three types of attack by an individual, i.e. input, processing, and transmission level attacks. One of the major attacks on biometric recognition identified by the researcher community is spoofing, which directly affects the enrollment or the detection process of a recognition system [17]. To analyze the effect of spoofing on gait recognition, researchers have examined dynamic patterns obtained from gait detection methods. The results have adequately combined the design and movement cues to judge the performance depreciation using the spoofing dataset of gait, which was recorded at the University of Southampton. Out of the many types of spoofing, clothing spoofing was selected for the experimental analysis, as it is one of the most easily adoptable factors that can be used by persons to alter their gait silhouette. Normally there can be two types of error encountered by a biometric authentication system, i.e. rejecting a genuine user and accepting an impostor. That's why the performance of any biometric system is judged by looking at its false acceptance rate and false rejection rate.

10.10. Environmental factors

There are many other factors that can affect the gait of a human, which involves both physical characteristics of an individual and following environmental factors [42]:

- Camera factors like gait capturing angles
- Time Elapsed
- Walking behavior like walking by carrying something in hand or by different clothes or shoes.
- Factors, like injury caused due to accident, quality of captured images etc.

Every factor is correlated with each other. For instance, changing shoes while walking may lead to a change in walking speed. Even a change surface for walking can impact the walking speed of a person. These correlations between various factors cannot be neglected as they significantly control or impact the constituent component of a person's gait [4]. Sivapalan et al. [44] have studied the impact of gait affecting factors, including environmental ones like viewing angles, lighting conditions, etc., and person-based factors like clothing change, the carrying of goods, and even mood variation of the person under consideration. Different factors affect individuals in different ways, and we can only understand the interactions between environmental factors and our health in terms of risk. An important and major factor affecting human body stability and direction of walking is the support basis size; the factors and moment developed in contact between the legs and

background are necessary to be analyzed, especially at the moment of external factor action or when the person has some important disabilities [32]. All this information can be collected and analyzed to establish the methodologies to evaluate the importance and size of disabilities or the impact of the environmental factors on the human behaviors.

10.11. Synthesis analysis

In this section, we present a synthesis analysis of gait recognition as follows: -

- In order to achieve good accuracy rates, a researcher must utilize hybrid feature selection and extraction methods as accuracy is directly related to the quality of feature selection and extraction methods [12].
- Every individual has a different walking style, so gait recognition of an individual is undoubtedly a challenge.
- Gait of the human can be significantly influenced by the physical characteristics of the subject and environmental factors.
- Different factors like camera factor, the time elapsed, injury, disguise, and image quality affect the gait of the individual.
- Camera parameters affect the measurement and viewpoint of gait.
- In order to conduct various experiments standard datasets must be available.
- The most widely used methods for extracting and selecting the features for the gait recognition task are frequency transformation, discrete cosine transformation, ID-radon transformation, statistics methods, and PCA methods.
- It is also observed that mostly used data recording and processing techniques are cameras.
- RGB-D Kinect camera is used for the purpose of data recording and processing where R, G, B represents red, green, blue color respectively, and D represents the depth.

11. Conclusion and future directions

We make a comparative survey of various recent techniques used to recognize the gait of an individual. Gait recognition is a technique that is used to identify a person using their gait cycle, which is also known as a human walking cycle. It has been done in two phases, i.e. stance phase and the swing phase. The initial contact that is heel strike marks the start of the stance phase while it ends with toe-off. In the Second phase, i.e. swing phase, the leg remains in the air. It starts with acceleration and ends with de-acceleration. We have also discussed the various databases that are used for gait recognition. The various databases discussed are CMU MoBo Dataset, Georgia Tech Dataset, and UMD HID Dataset, etc. There are Hidden Markov Model, Machine Learning, and Bayesian classification techniques for the classification of gait. Future perspectives involve creating a sufficiently large size corpus of gait data by considering many distinct angles and views. Also from these survey findings, it's an open challenge for the researchers in the area of biometrics, to use gait modality for the successful identification of an individual including the gender, age, and nationality even. So such kind of developments undoubtedly helps in forensic and criminal investigations. There is a need of developing some efficient and strong feature extraction and classification algorithms to identify an individual and to classify the gender of an individual. Deep Learning-based methodologies will definitely boost the system performance.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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