CHAPTER 1

Introduction

Human identification and verification systems use a variety of biometric traits like fingerprints, voice, palm prints, iris, gait, and the face. Each has its own unique set of advantages and disadvantages. Among these biometrics, gait recognition aims to recognize an individual based on the way they walk and has been studied in a wide range of computer vision problems. The advantages of gait over other biometric traits are that it can be applied unobtrusively and offers potential for distance-based identification at low resolution with few image pixels [48]. Since human gait analysis includes both subjective and objective components, the presence of covariate issues has a significant impact on gait recognition performances. The covariates are the continuous variable that affects an outcome [26]. Human gait is influenced by variables like clothing, carrying conditions, walking surface, camera viewing, walking speed, etc. These are the covariate conditions in human gait analysis.As a result, whether gait can be used as a unique individual identifier or not, like other biometric indices, is a continuing research problem in the computer vision community [82]. There have been numerous approaches and frameworks reported in the past to address covariate issues in gait-based human identification, and this remains a recurring challenge. According to the studies, gait recognition using a model-free approach has been mostly used for empirical studies. The main aim of this research is to improve the performance of gait recognition, which is influenced by covariate factors, by employing gait representation approaches that are currently in use. This study explores a variety of gait representation techniques, including model-free and model-based gait analysis methods, with the goal of addressing the various covariate challenges associated with gait recognition.

Early studies on gait were primarily used in the medical field to monitor and track the health of a patient's walking pattern, with or without injuries, with the help of devices that were attached to the patient's body or could sense his or her movements. However, numerous studies on gait have shown that gait recognition is a unique method for identifying a person from a distance. In 1994, the gait analysis algorithm to study human gait patterns was developed by Niyogi and Adelson on a small gait dataset[65]. Subsequently, the first gait-based human identification system was developed and implemented by a group of the research team for a security system for the US Embassy[64]

Gait recognition has been a topic of research for many years, and early studies did report high recognition rates for gait-based human identification. However, these studies typically had small sample sizes and did not account for realistic covariate factors that could affect gait recognition performance in real-world scenarios. More recently, researchers have focused on developing more robust gait representations that can handle a wider range of covariate factors. This includes factors such as clothing styles, carrying objects while walking, changes in walking surface, walking speed, footwear, and viewing angle, among others. By developing gait representations that are more robust to these factors, researchers hope to improve the performance of gait-based human identification systems in real-world scenarios. Some of the techniques incorporated in this work include constructing more robust gait representations using deep learning-based methods, which can learn more complex and abstract features from gait data, and data augmentation techniques, which can help to create a more diverse set of training data that better capture the range of covariate factors that can affect gait recognition performance.

Visual gait analysis is one of the most popular approaches to analyzing gait, and it involves using cameras and image processing techniques to track and analyze a person's movements. Human walking in normal conditions differs from human walking under clothing and baggage conditions, making it difficult to identify the person when the covariates change. In this work, model-free gait analysis is first investigated to see how it addresses the covariate issues in gait recognition. For the model-free analysis, GEI(Gait Energy Image) gait template is adopted. GEI is an enhanced Spatio-temporal gait representation for efficient individual recognition [31]. GEI template is generated by averaging the binary silhouette image over one gait cycle. It is expected that the GEI will contain more spatial features and fewer temporal features[51]. Finally, GEI template is preprocessed using a Gaussian filter and edge detection operator to preserve the fundamental structural characteristics of the GEI image.

The research work also presents the use of model-based gait analysis and human pose estimation techniques to address covariate issues in gait analysis. The approach involves using high-resolution images and extracting human body point instances to estimate gait patterns under various environmental factors. The research proposes a method for representing gait patterns for analysis despite the presence of covariate issues. The human pose estimation technique, which is commonly used for action recognition, such as in sports and yoga, is identified as a potentially effective method for gait pattern analysis. This work also proposes a method for creating a unique gait pattern of an individual for gait analysis with covariate issues using the pose estimation technique. Additionally, it underscores the significant potential of human pose estimation for individual recognition, irrespective of covariate conditions.

Overall, the research suggests a promising approach for gait analysis deploying model-free and model-based gait analysis approaches, which could have implications for a variety of applications, including clinical gait analysis and surveillance.

1.1 Problem Statement:

Vision-based gait analysis has emerged as a promising technology for human identification in recent years. Gait analysis involves analyzing the human walking pattern to extract features that can be used to identify individuals. However, the accuracy of gait analysis is affected by various covariate conditions such as different walking surfaces, clothing, lighting, and weather conditions. The problem scope of this research is to explore the effectiveness of vision-based gait analysis for human identification under varying covariate conditions. The main aim is to develop an effective gait representation using various gait analysis approaches that can be used for human identification regardless of the covariate conditions. To achieve this aim, various computer vision techniques such as deep learning, image processing, and pattern recognition are used. The study focuses on identifying the most relevant features for gait analysis that can improve the accuracy of the identification system. Overall, the research aims to contribute to the development of an effective and reliable human identification system that can be used for security and surveillance purposes in different settings and covariate conditions.

1.2 Motivation

In recent years, gait recognition has become a prominent research topic, and there are numerous real-world applications for gait recognition. These applications include human identification, healthcare monitoring, security and surveillance systems. This work aims to explore the existing state-of-the-art vision-based gait analysis and, develop a method to improve gait recognition performance under covariate conditions. Listed below are the prime motivations behind taking this research work:

- Traditional identification methods such as fingerprint and facial recognition have limitations, and they can be easily manipulated. Vision-based gait analysis offers an alternative approach that can overcome some of these limitations.
- Gait-based identification is a non-intrusive biometric technology that does not require physical contact with the person being identified. This makes it a more comfortable and convenient alternative to traditional biometric identification methods such as fingerprint or iris scanning. It can identify individuals from a distance, making it ideal for applications such as surveillance systems and crowd monitoring.
- Vision-based gait analysis can contribute to advancements in human-computer interaction, particularly in the field of biometric authentication. By integrating gait analysis into user authentication systems, it may be possible to develop more secure and user-friendly interfaces, allowing individuals to access devices or systems simply by the way they walk.
- To explore the effectiveness of vision-based gait analysis under varying covariate conditions, including different walking surfaces, clothing, and carrying conditions. By addressing these covariate factors, we can develop a system that can accurately identify individuals in a variety of situations, improving the effectiveness of surveillance and security measures

1.3 Literature survey

The use of gait-based human identification has gained significant attention in recent years due to its non-intrusive nature and potential for widespread implementation. However, one of the major challenges in gait-based identification is the presence of covariate conditions, such as changes in clothing, footwear, carrying conditions, and environmental factors, that can significantly affect the gait patterns of individuals and thus, compromise the recognition performance.

To address this challenge, several effective methods have been proposed in the literature. One such method is the use of multi-view gait recognition, which involves capturing gait data from multiple camera views and fusing the data to improve recognition performance.

In this section, the emphasis of the discussion is on gait analysis approaches, gait datasets, human gait under covariate issues, gait feature representation, and gait classification. Several studies have been conducted to explore the effectiveness of vision-based gait analysis for human identification, taking into account covariate conditions such as different walking speeds, clothing, carrying conditions, and surface conditions.

1.3.1 Gait analysis approaches

Gait analysis is an important tool for understanding human movement, assessing gait abnormalities, and monitoring treatment progress. Gait analysis can be conducted using different approaches, each with its own strengths and limitations. This literature survey aims to review the various gait analysis approaches and highlight their applications, advantages, and limitations. Predominantly gait analysis approaches depend on different types of instruments used for capturing gait data. Some commonly used instrumented approaches include:

i Motion Capture Systems: Motion capture systems use cameras to track the movement of reflective markers placed on various body segments. This approach can provide detailed information about joint angles, timing, and movement patterns. However, the set-up and calibration of the system can be time-consuming, and the use of markers can interfere with natural movement.

ii Force Plates: Force plates are used to measure the ground reaction forces exerted by the feet during walking. This approach can provide information about the timing and magnitude of forces exerted during different phases of gait. However, force plates are expensive and require a specialized laboratory setup.

iii Wearable Sensors: Wearable sensors such as accelerometers, gyroscopes, and pressure sensors can be used to capture gait data in a more naturalistic setting. This approach can provide continuous and objective data over an extended period. However, the accuracy of wearable sensors can be affected by factors such as sensor placement and movement artifacts.

In general, gait analysis approaches are divided into two types: Vision-based/Image-based and Sensor-based. The taxonomy of human gait analysis along with gait acquisition techniques are

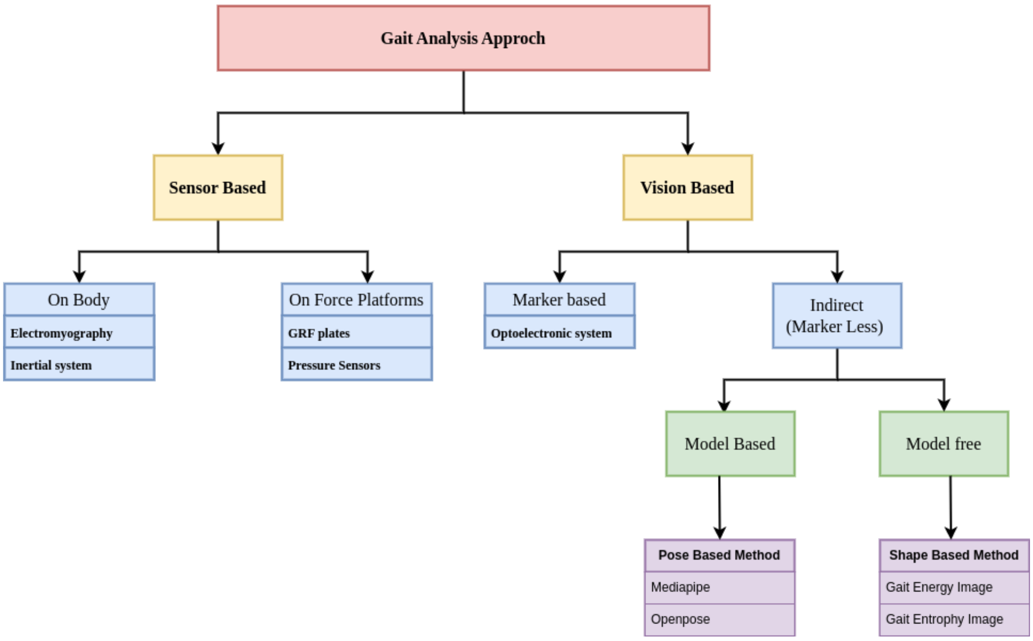

Figure 1.1: Human gait analysis approaches and acquisition techniques

shown in Fig. 1.1. In the vision-based approach, Marker-based(direct) and markerless (indirect) are the two methods adopted for gait feature representation and analysis of human gait patterns. The marker-based approach gait analysis captures the kinematic parameter of the human walking pattern using the optoelectronic active or passive marker and is suitable for short distance[74]. In the marker-less technique, a model-free and model-based non-marker is used to analyze human gait patterns. Vision-based or Image-based gait analysis is one of the most common approaches used in human recognition based on human gait in surveillance[53]. From a surveillance perspective, gait analysis with vision-based technology is a more precise and holistic method of human identification[44]. Also, a cost-effective approach for real-time application[32]. However, there are challenges in the vision-based approach for addressing multi-view issues in gait recognition[68]. In a sensor-based approach, sensing devices are placed either on the human subject or, on the floor[58]. In terms of portability and data acquisition, gait analysis using a sensor-based approach may be more convenient than vision-based analysis. However, gait feature acquisition is dependent on subject movement and correct sensing device position, and it is not cost-effective[1].

The primary goal of this research work is to explore vision-based gait analysis for human identification under covariate conditions. We present a summary of the survey literature on vision-based gait analysis for human identification in Table 1.1

Table 1.1: Summary of vision-based survey articles that focused on human identification using gait

Cite	Year	Work focused on
Anubha et al. [66]	2023	This work explores the performance of deep learning models in covariate conditions, focusing on data acquisition, input, dataset, preprocessing, feature extraction, transformation, activation function, classification, and training parameters.
Khan et al.[39]	2021	History an overview of different sensing modalities feature extraction techniques and their classification into different groups, comparison of recognition accuracy, 11 covariate factors and summary of 44 databases is presented
Sepas et al.[76]	2021	The study explores how different types of feature representations can be used to train deep learning models for gait recognition on 15 different datasets for various gait recognition experiments.
Sahu et al.[73]	2020	The study explores the framework for gait recognition using model-based and model-free gait analysis techniques and discusses their respective advantages and disadvantages.
Nithyakani et al.[62]	2020	Highlight the importance of gait analysis in understanding and enhancing human movement through the use of various gait approaches and applications.
Saxe et al.[75]	2020	The study investigates how various machine learning techniques can be applied to gait recognition, along with how gait recognition can be classified and categorized to better understand human movement patterns.
Singh et al. [80]	2019	categorization of techniques used in computer vision and sensor processing based on different covariate factors using larger benchmark dataset is discussed
Rida et al.[70]	2018	Gait recognition rates is evaluated against three covariate condition for Robust gait recognition techniques
Wang et al.[89]	2018	Focusing on various sensing methods, feature representation and fusion, classification algorithms, and gait with covariate conditions

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Table 1.1 – *Continued from previous page*

Cite	Year	Work focused on
Connor et al.[19]	2018	Data acquisition modalities, features extraction techniques using model-based and model-free approaches for seven covariate factors are examined
Prakash et al.[68]	2018	represented Vision and sensor-based approaches along with public available datasets
Connie et al.[18]	2015	Cross-view gait recognition is investigated
Lee et al.[42]	2014	vision-based techniques for human identification with 17 gait datasets is discussed.
Chai et al.[13]	2011	Focusing more on gait recognition techniques, databases, and challenges
Zhang et al.[92]	2010	Gait recognition in Model-based and model-free approaches, data reduction methods and classification techniques are discussed.
Liu et al[48]	2009	Empirical study on model-based and model-free approaches

1.3.2 Gait dataset

Gait datasets are collections of human gait data, including kinematic and kinetic measurements, captured using various sensors and equipment. These datasets are used for various applications such as biomechanical research, clinical analysis, human motion analysis, and gait recognition. Over the years, researchers have developed several gait datasets, and there have been numerous studies analyzing and benchmarking these datasets. In this literature survey, the summary of the prominent vision-based gait datasets for human identification with their characteristics like the number of sequences, subjects, covariate conditions, and frame rate devices in Table **??**. These dataset has been used in many empirical studies towards developing new gait analysis techniques, new gait recognition algorithms, segmentation, and classification techniques. Furthermore, the benchmarking of newly created gait datasets against these prominent datasets can ensure their accuracy and reliability.

In this research, we utilize the CASIA-B dataset as a primary benchmark for empirical and experimental analysis. The CASIA-B gait dataset, developed by the Chinese Academy of Sciences' Institute of Automation (CASIA), stands as a comprehensive and influential collection of gait sequences. It plays a pivotal role in the domain of gait analysis, serving as a valuable resource for the study of human gait patterns and the development of gait recognition algorithms. With its extensive coverage of subjects and sessions, encompassing diverse walking conditions, speeds, and perspectives, the CASIA-B dataset facilitates in-depth research into the inherent variability of human gait. Its significance is underscored by its potential to enhance accuracy and robustness in gait analysis and recognition algorithms, thereby contributing to advancements in security and other practical applications.

Table 1.2: Vision-based gait datasets and their characteristics

Data Set	Year	No.of subjects	No. of sequence	Covariate condition	Frame rate	No. camera and Devices
SOTON small Dataset [23]	2001	12	NA	Indoor with smooth floor,shoes and clothing covariates	25fps	1 camera
HiD-UMD-1 [22]	2001	25	100	4-view variates, Walking covariate, outdoor	NA	1 camera
HiD-UMD-2 [22]	2001	55	220	T-shape, walking covariates, outdoor	NA	2 cameras

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Table 1.2 – continued from previous page

Data Set	Year	No.of subjects	No. of sequence	Covariate condition	Frame rate	No. camera and Devices
CASIA-B[104]	2005	124	13640	11-view variation, clothing and carrying	25fps	11 cameras
TUM-IITKGP [34]	2010	35	840	Occlusion, carry condition and walking variation	NA	1camera
OU-ISIR[54]	2012	122	1870	Walking speed and clothing covaraites	30fps	25 cameras
OU-ISIR [36]	2012	4007	NA	8 multiview variation with constant speed	30fps	2 cameras
AVA-Multiview [50]	2013	20	1200	Multiview	25fps	6 cameras
OU-LP-Bag[87]	2018	62528	NA	Carrying object variation, indoor	25fps	1 camera
OU-MVLP[95]	2020	10307	NA	Cross view covariates,indoor	25fps	7 cameras

1.3.3 Covariate issues in human gait analysis

Human gait refers to the pattern of movement of a person's limbs and body during walking. It is a complex process that involves the coordination of various muscles and joints and is influenced by many factors, including age, gender, body weight, and physical fitness. However, gait analysis can be further complicated by covariate issues, which refer to other factors that can affect the measurement of gait. For example, environmental factors such as terrain and footwear can affect gait or appearance factors such as clothing, carrying conditions, and different view angles can affect. Clothing Clothing variations pose a significant challenge in gait recognition systems. Different types of clothing can affect the appearance and motion patterns of individuals, making it difficult to extract consistent gait features [39].

Gait recognition performance is greatly influenced by variations in viewing angles and individuals carrying objects. Changes in viewpoint affect the appearance and spatial relationships of body parts, making it challenging to match gait patterns accurately. To tackle this covariate, researchers have proposed methods such as gradient orientation analysis, skeleton-based representations, and multi-view fusion techniques [39].

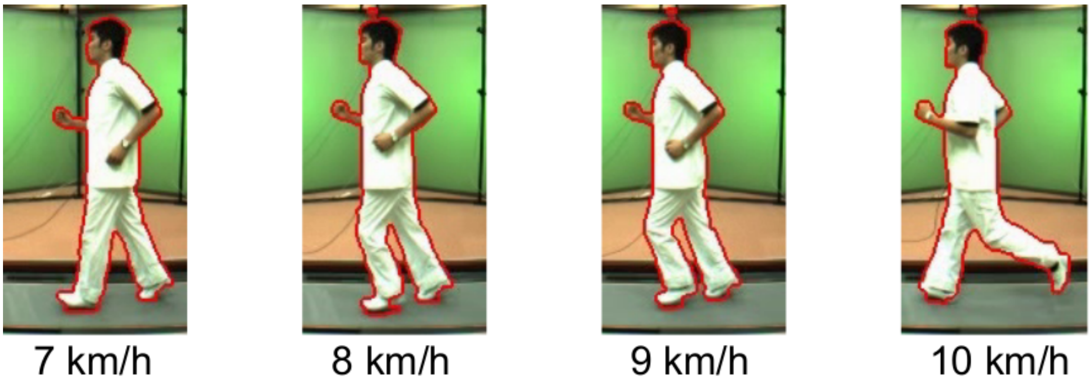
The walking surface and footwear worn during gait acquisition introduce additional covariate factors that impact recognition accuracy. Studies have shown that gait patterns are influenced by the characteristics of the walking surface, such as grass, sand, or carpet. Footwear variations, including different shoe types and barefoot walking, also contribute to changes in gait dynamics. Researchers have proposed approaches such as entropy computation, gradient orientation analysis, and motion characteristics extraction to develop walking surface invariant and shoe invariant gait recognition systems [39], [5], [6]. These techniques aim to mitigate the influence of surface and footwear covariates, enhancing the recognition performance across different walking conditions. Also, the viewpoint covariates can have a significant impact on gait recognition because they can alter the way a person walks and make it more difficult to recognize them based on their gait patterns. View-point covariates refer to changes in the camera viewpoint that can occur due to factors such as camera placement, camera angle, and camera movement [10]. Sample video sequences of commonly occurring conditions are shown in Figure 4.3.

In addition, different gait analysis techniques may have different levels of sensitivity to covariate issues. For example, traditional gait analysis methods such as visual observation may be less sensitive to covariate issues than more advanced techniques such as motion capture or force plate analysis. Therefore, to address these covariate conditions, researchers have developed a variety of gait recognition algorithms that use different techniques to account for variations in gait patterns. For example, some algorithms may use machine learning techniques to identify common patterns in gait data, while others may use statistical methods to account for covariate effects. Robust gait recognition based on partitioning and canonical correlation analysis by Lou et al [52]. This work proposes a gait recognition method that employs canonical correlation analysis (CCA) to handle covariate factors such as clothing and carrying with KNN classifier as a similarity measure of the correlation strength. The approach achieves high recognition rates over the existing method for all view angles. Yu et al [104] in their work suggested an evaluation method to compare the performance of various covariate conditions such as viewing, clothing, and carrying effect in gait recognition. This work also proposes an evaluation metric to calculate the correct classification rate by considering all the covariate conditions using a separate database for each covariate condition. A combination of static and dynamic gait features with a Gaussian filter is an effective method to reduce the effect of outliers in mult-view covariates in gait-based person identification [57, 37]. The experiment was carried out on smaller databases such as SOTON small DB and Oblique DB, and it was based on body trajectories points. When there is considerable view variation, a view transformation model using the auto-encoder method for gait feature extraction greatly improves recognition recognition rate and can achieve state-of-the-art performance [103, 107]. It is ideal for surveillance applications where it is not necessary to estimate the exact view angles between subjects and camera or any covariates condition involved. Chao et al. [14] proposed a novel approach for identifying a human from a set of discrete frames using a new network called GaitSet. The analysis result reflects a state-of-the-art recognition system. Alotaibi et al. [2], proposed the first classification technique based on CNN with a high precision of 92% using GEI as input and suggested identification of cross-view variance gait using deep CNN architecture. The work focuses on reducing covariates factors and strongly points out the efficient use of feature extraction and selection methods for better recognition performance. Liu et al. [49] have worked on gait-based gender recognition using two models with the CASIA B dataset. The first model uses a CNN pre-trained model with fully trained feature descriptors to extract the feature to train the SVM. The second model involves varying the VGGNet-16 using an L2 norm to create VGGNet-SVM as the new architecture. The final result analysis shows that VGGNet-SVM shows a better result than Softmax with VGGNet-16 with an accuracy rate of 89.62%. Their work gives future directions for different gait-based applications. Hawas et al. [33] proposed a gait-based human identification using CNN and optical flow GEI, achieving over 95% accuracy and promising results to change in view angles. This work provides a motivation to investigate additional gait patterns and feature representations in an effort to improve the performance of gait recognition. A gait recognition method is proposed using a 3D CNN architecture along with gait energy images (GEI) as a condensed representation of the shape and motion of the human gait [27]. This approach effectively addresses challenges related to multiview and carrying conditions and achieves state-of-the-art results. An improved LeNet network is introduced to effectively handle covariate conditions associated with normal walking, various clothing types, and carrying objects by Shao et al. [77]. The work demonstrates the potential of employing deeper networks for larger databases by utilizing appropriate hyperparameter tuning. The model-based approach incorporating body pose estimation exhibits the potential to effectively address various covariate factors that influence gait recognition performances [45].

1.3.4 Gait representation

Gait representation is a critical step in gait recognition. It aims to extract the most discriminative and robust features that can distinguish individuals from their gait patterns. Various gait representations have been proposed in the literature, including silhouette-based methods, motion-based methods, and model-based methods. Silhouette-based methods extract features from binary images obtained by segmenting the walking person from the background. Motion-based methods analyze the temporal changes in the pixel values of the video frames to capture the dynamic information of the gait [69]. Model-based methods use mathematical models to represent the gait as a set of parameters [102, 45, 63]. The choice of the gait representation method depends on the specific application requirements and the characteristics of the gait dataset. The challenge of gait representation lies in dealing with the variations caused by covariate factors such as clothing, carrying objects, and walking speed. These variations can affect the accuracy and robustness of gait recognition. In this thesis, we will investigate various gait representation methods to handle different covariate factors. We also propose a novel gait representation method that can effectively deal with the variations caused by covariate factors and improve the accuracy of gait recognition. The following subsections discusses the various gait representation approaches

(a) Person in normal walking with clothing and carrying covariate conditions



(b) Walking speed covariate conditions

(c) Viewing angle covariate conditions

(d) Walking surface covariate conditions

Figure 1.2: Gait video sequences under covariate conditions from various standard dataset

1.3.4.1 Gait representation using Model-based approach

Model-based methods for gait representation are a type of approach that uses mathematical models or structural models, an analytic model or a statistical model to represent the gait as a set of parameters. These models are based on biomechanical principles of human walking and aim to capture the natural dynamics and kinematics of gait. One of the main advantages of model-based methods is their ability to capture the kinematics parameters of gait. By explicitly modeling the movements of the body during walking, these methods can capture small variations in gait patterns that may be unique to each individual. This can enable more accurate human identification based on their gait. Much significant research is seen on using models of human gait using structural models such as 2D and 3D,[88, 88, 105]. The existing works have been more towards using 2D model for its better computational complexity. Work has been reported on using structural models and mathematical models to estimate the gait parameters of the human body.[88, 105]. According to studies, the use of a model-based approach to extract gait parameters from a human body model may be affected by changes in the appearance of the model caused by factors such as clothing and carrying conditions. These changes could lead to incorrect estimation of the gait parameters. Model parameter estimation such as the angular motion of thigh and knee for human walking using analytic models of human motion to create gait signature is proposed [101].

1.3.4.2 Gait representation using model-free approach

Gait representation using a model-free approach involves using computer vision techniques to extract features from video data of human gait, without relying on a predefined mathematical. In Model-free approaches, the emphasis is either on silhouette shapes or the entire movement of the human body, rather than modeling the entire human body. The model-free model is not responsive to silhouette consistency, so it benefits from low computational costs. One common method for vision-based gait representation using a model-free approach is based on the extraction of spatio-temporal features from the video data. These features capture the shape and motion of the body during walking and can be used to represent the gait pattern.

In model-free gait analysis, the detection and tracking of moving objects in a video sequence are typically performed using the background subtraction technique. The primary goal of this technique is to separate the moving objects (individuals walking) from the background (the static environment). However, the accuracy of gait recognition in model-free analysis can be affected by various challenges associated with background subtraction such as shadows, illumination changes, dynamic scenes, and Camera motion [67]. Efficient techniques and approaches for gait feature extraction and preprocessing, which uses model-free gait templates, have been extensively studied for gait recognition system. An adaptive silhouette extraction algorithm was utilized to segment gait images [47]. The authors performed post-processing techniques to obtain normalized silhouettes with reduced noise. Additionally, they proposed a novel extraction approach based on the outermost contour of the silhouettes. Another study by Hu.ng et al [61] developed a method for extracting gait features from silhouettes. The authors applied a smoothing operation on the extracted features to enhance their quality and reliability. P. Das et al [59] suggested a pre-processing step for obtaining optimal silhouettes for feature extraction. This involved utilizing silhouette noise removal techniques to eliminate randomly spread intensity errors and error connections present in large blobs within the silhouettes. Chen et al [44] employed parallel Hidden Markov Models (HMMs) to describe the features of human gait. They proposed using the Gait Energy Image (GEI) as a gait feature, which captures human motion grouping in a single image while preserving fine details. These above studies emphasize the importance of accurate gait feature extraction and preprocessing steps to improve the quality and reliability of gait recognition systems using a model-free gait analysis approach.

1.3.4.3 Gait classification

Gait classification is the subject of the present study. Developments in sensor, computer vision, and machine learning technologies continue to contribute to the creation of more robust and efficient gait recognition systems.

Gait classification refers to the process of analyzing and categorizing human walking or running patterns based on various characteristics and features. It involves the extraction of relevant gait features from video or sensor data and the application of classification algorithms to identify and differentiate individuals based on their unique gait patterns.

Gait classification techniques aim to capture the distinctive aspects of an individual's gait, including stride length, step duration, walking speed, body posture, joint angles, and motion trajectories. These features are then used to develop mathematical models or machine learning algorithms that can classify and recognize individuals based on their gait signatures.

Classification algorithms such as the K-nearest neighbor (KNN) classifier and Support

Vector Machine (SVM) have indeed been widely used in gait classification for identification systems. These algorithms have demonstrated their effectiveness in distinguishing individuals based on their gait patterns.Collins et al [17]. utilized the nearest neighbor classification approach to template scores in their research, which involved matching gait features to reference patterns. This technique allowed them to classify individuals based on the similarity of their gait patterns to the template scores. In addition to the KNN classifier, other classification algorithms have also been applied in gait recognition studies. For instance, Xue et al [100] employed SVM, a linear classifier, to classify wavelet features extracted from Gait Energy Images (GEI). SVM constructs a hyperplane in the feature space to separate different classes, enabling accurate classification of gait patterns. Lishani et al. [46] conducted an evaluation of gait recognition criteria using the KNN classifier. Their research aimed to assess the effectiveness of the KNN algorithm in distinguishing between different individuals based on their gait patterns. The study mentioned by Nandy et al [56] emphasizes the influence of clothing covariate on gait energy image (GEnI), which is a representation of gait patterns. The authors used three classifier combinations, namely Support Vector Machine (SVM), k-nearest Neighbors (k-NN), and minimum distance classifier, to evaluate the accuracy of clothing covariate on GEnI. They achieved an accuracy of 80% using SVM and MDC, outperforming the conventional k-NN classifier with multi-class SVM. Alotiabi et al [2] proposed a classification technique based on Convolutional Neural Networks (CNN) for gait recognition. They achieved a high precision of 92% by using a Gait Energy Image (GEI) as input to the CNN model. The study suggests the identification of cross-view variance gait patterns using a deep CNN architecture. Another experimental study by Wu et al [97] focused on gait recognition using deep CNN. They specifically addressed the challenges of cross-view and cross-walking scenarios. The study achieved an average accuracy of 94% on the CASIA dataset and 98% on the OUISIR dataset, indicating the effectiveness of deep CNN for gait recognition in challenging conditions. These studies demonstrate the potential of machine learning, especially Deeplearning techniques like CNN, in improving the accuracy of gait recognition systems.

1.4 Research objectives

This thesis explores various methods for improving human identification accuracy through gait analysis, addressing challenges such as covariates and view-invariant. Initially, a model-free gait analysis for human identification is investigated to address the issue of covariates that can impact identification accuracy. The thesis proposes a method to reduce these covariate conditions and evaluates its robustness using various machine learning algorithms and CNN models. Additionally, the thesis presents a small dataset for human identification on varying surface conditions, which is evaluated using state-of-the-art classification models and a custom CNN model. Finally, a model-based gait analysis using human pose estimation is proposed to address the view-invariant issue in human identification. This method uses body key points to identify a human regardless of covariates.

- To develop an accurate and reliable system using model-free gait templates for human identification that can be used in a variety of settings and covariate conditions, contributing to the safety and security of individuals and communities
- To develop a human gait dataset from a natural setting on different walking surface conditions
- To develop methods for subject classification irrespective of covariate conditions
- To develop a human identification method for surface covariate conditions
- To develop a method for addressing multiview covariate issues in gait recognition

These objectives are accomplished and implemented using the existing vision gait dataset and the proposed dataset in the research work.

1.5 Thesis outline

In Chapter 2, we investigate vision-based model-free gait analysis approaches, datasets, feature representation techniques, and classification methods in order to address the challenges posed by covariate conditions in gait-based human identification. Additionally, we review a selection of parallel studies that focus on human identification with covariate conditions using gait, specifically examining their performance outcomes. Furthermore, we provide a comprehensive background study on model-free gait analysis approaches for human identification. The subsequent sections of this chapter present related works that highlight effective strategies for mitigating covariate conditions in model-free gait analysis, resulting in significant improvements in recognition performance under covariate conditions.

In Chapter 3, we introduce a small gait dataset for human identification in natural environments with varying walking surface conditions. The dataset contains gait sequences of 50 subjects walking on three different surfaces: concrete, grass and slope. Each subject was recorded from two different viewing angles: 90 degree and 45 degree. The dataset was captured using two smartphone cameras with 48 and 64 megapixels. On the proposed dataset, we evaluate the performance of a state-of-the-art CNN model for gait recognition and provide baseline results. The work also proposes a convolutional neural network (CNN) model by optimizing the hyperparameters of an improved LeNet architecture used for gait recognition. The experimental results indicate that the proposed CNN model can perform comparably to existing state-of-the-art models on a relevant database.

In chapter 4, investigates and proposes a new method for human gait recognition using a CNN model and feature fusion technique. The study aims to overcome the limitations of existing CNN-based gait recognition methods by making the recognition process more robust to covariate conditions, which are factors that can affect the appearance of a person's gait, such as clothing, shoes, and walking surface. Additionally, a Feature fusion-based method is developed for gait recognition irrespective covariate conditions. The CASIA-B standard dataset is used to perform analyses of the proposed methods and compare them to existing methods.

In chapter 5, The challenges of multiview issues in gait recognition are addressed. A method for reducing the effect of multiview is developed using various existing gait representation techniques. One such method is the use of a model-free gait analysis approach. Also, we mentioned the effectiveness of the existing gait representation methods in tackling the influence of covariate conditions that need to be enhanced. Finally, view-invariant gait recognition using dynamic body key points is proposed, along with a technique to create an individual's unique gait pattern.

In Chapter 6, we highlight the importance of our work concerning gait analysis for human identification under covariate conditions and discuss some possible future work.