Heel-Strike Detection for Angle Invariant Gait Pattern Recognition

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Certificate

This is to certify that the work in the project entitled *Heel-Strike Detection for Angle Invariant Gait Pattern Recognition* by *Priyanka Agrawal* and *Tripti Samal* is a record of their work carried out under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of *Bachelor of Technology* in *Computer Science and Engineering.*

Pankaj K Sa

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Priyanka Agrawal
Tripti Samal

Abstract

Gait is one of the most important biometric modality for recognition in the field of computer vision. The aim of gait recognition is to identify people by analysis of motion characteristics. Heel-Strike detection is a widely used cue for gait recognition in a visual surveillance environment. Most algorithms work best when a subject walks parallel to the camera. However, in real life scenario, it is not practical to assume this. Thus, we need a view independent approach. In this thesis, given a set of silhouette images of a person walking, a viewpoint invariance method is proposed to find gait feature heel-strike. Results obtained from the simulation of CASIA Gait Database are compared with the ground truth.

***Keywords*:** Gait Recognition, Heel-Strike, Viewpoint Invariance, Surveillance

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Chapter 1

Introduction

1.1 Biometrics

Biometric technology is defined as an automated method of identifying or authenticating the identity of a person based on physiological or behavioural characteristics such as those based on retinal or iris scanning, fingerprints, face recognition, gait recognition, signature etc. Biometric technology provides a reliable and cost effective way to distinguish identities and for authentication purposes. The method of identification based on biometric characteristics is preferred over traditional passwords and PIN based methods for various reasons such as: The person to be identified is required to be physically present at the time-of-identification. Biometric techniques avert the need to remember a password or carry a token. Primary advantage of biometrics over token-based or knowledge-based approach is that, it cannot be stolen or misplaced. Three steps that include biometrics are capture, process, enrol and a verification process. Biometric identification system needs to compare a registered biometric sample against a newly captured biometric sample. During capture process, biometric trait is captured via sensing device or a video camera. Next phase is enrolment. Here a mathematical representation of the sample is registered or stored for future comparison during an authentication. Then, distinguishing characteristics from the raw biometric sample is extracted for further processing.

Several biometric traits such as iris, fingerprint, signature, DNA, voice, face, gait are the key research areas. All biometric identifiers can be divided into two standard groups:

1. Physiological (or passive)
2. Behavioural (or active)

Feature that are used in physiological biometrics do not change by influence or motion. Physiological system deals with statistical characteristic of a person: palm print, fingerprint, hand geometry, iris recognition, DNA, face recognition etc. On the other hand, behavioural biometric pays attention to the action of a person. It is based on the data derived from an action indirectly. Time is used as a measurement metric in case of behavioural biometric. Gait, voice etc. are some of the examples of behavioural biometric traits.

1.2 Gait Biometrics

Gait is defined as a particular way of moving on foot. Gait as a biometric is an important research problem in the field of computer vision. Goal is identification of a person through analysis of gait pattern. Because the technique can be applied remotely without the cooperation of subject, it has been used in surveillance, access control etc. Gait recognition has many advantages over traditional methods. For instance, bank robbers often wear mask, gloves which invalidate face recognition, finger print recognition etc. In this case gait would probably be the only technique useful for recognition. Other advantages of gait biometric are:

1. Distance Recognition: The gait of a subject can be captured at a distance.
2. Reduced Detail: Gait does not require the image that has been captured to be of high resolution.
3. Difficult to conceal: The gait of an individual is difficult to disguise. With other biometric trait such as face recognition, an individual's face can easily be altered.

From a technical point of view motion analysis includes object detection and recognition, tracking and behaviour understanding. A significant challenge in this is an accurate background subtraction to separate the walking subject.

1.3 Problem description

We are given a set of background-subtracted silhouette images of a person walking. We are required to observe the gait pattern and find heel-strikes a gait feature for recognition – using a method which is angle invariant. A silhouette is a featureless image that gives the shadow (shape) of an object; it is obtained by background subtraction. Background subtraction is the process in which foreground is extracted for further processing. Figure 1.1 shows a background-subtracted image.

Heel-strike is the phase in walking cycle when the foot (heel) strikes the ground.

Figure 1.1: A background subtracted image

By angle- invariant method, it is meant that a method that will work independent of the angle at which the camera captures the image of the subject. Cameras are placed such that a subject can be viewed at different angles: lateral view or perspective view. This is illustrated in the figure 1.2:

In the figure, *camera1* is placed at about 45° to the subject (perspective view) and *camera2* is placed at an angle 0° to the subject (lateral view). Most of the gait recognition approaches are based upon the assumption that walking direction is normal to the camera viewpoint. In real surveillance circumstances, a system that

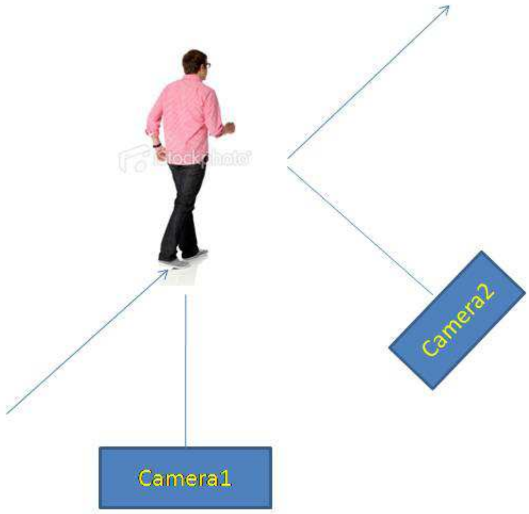

Figure 1.2: A background subtracted image

operates in an unconstrained environment where the person walks at an arbitrary angle to the camera is necessary, so an approach towards angle-invariant gait recognition is needed. Heel-strike detection is an important process in analysis of a person at distance; this information can be used to find the walking direction of a person.

1.4 Motivation

1. Gait recognition technique works in a *non-cooperative environment*, i.e., it can be carried out remotely without the cooperation of the subject.

2. In real surveillance scenarios, a system that operates in an *unconstrained environment* is necessary, so an approach towards angle-invariant gait recognition is needed.

3. *View-independent* gait analysis aims at synthesizing the lateral view of a walking subject without camera calibration starting from successful results on gait biometrics from a lateral view.

1.5 Database

The Institute of Automation, Chinese Academy of Science (CASIA) provides the CASIA data base to provide data for the development of gait recognition algorithms. In the CASIA dataset there are 3 set of datasets:

1. Dataset A (standard dataset)
2. Dataset B (multi-view dataset)
3. Dataset C (infrared dataset)

In our project, experiment is done with dataset A. Dataset A was created including 20 persons on $Dec.10, 2011$. Each person has 12 image sequences, 4 sequences for each of the three directions, i.e. parallel, 45° and 90° to the image plane. The size of Dataset A is about $2.2GB$ and the database includes 19139 images.

Chapter 2

Previous work

Some of the earliest works in gait recognition included that of Johansson who in his paper "Visual motion perception" used lights affixed to joints of human body and showed the motion sequences of the lights as a person walks. It was used in identification of gender and in cases where the observer was familiar with the walking subject, the identity of the walker. Similar to this, Cutting et.al used Moving Light Displays (MLD) and showed human person identification results and gender classification results [1]. Various sensors were developed for gait phase identification, which include foot switches, force sensitive resistors (FSRs), accelerometers, pendulum resistors and goniometers. One of the first foot sensors proposed was a heel switch which detected heel strike during normal gait. None of the above mentioned sensors achieved results with accuracy greater than 95%. Consequently, Popovic, et.al's proposed a gait identification sensor with three FSRs, an inclinometer and a rule-based observer. This sensor detected heel-off, swing phase, heel strike and mid stance with an accuracy greater than 99% [3]. Nixon et. al proposed another method for detection of heel-strikes. Given a series of frames representing the gait trajectory model, the key frames are extracted in which the heel-strikes take place. The method proposed is based on the observation that the foot of the striking leg stays at the same position for 50% of the gait-cycle time while the rest of the body moves forward. An accumulator map, defined as the number of silhouette pixels in (i,j)th position, is derived. It is used to determine the parts of the body remaining at the same place for a longer time and hence the frame with heel-strike is detected as it has a relatively higher distribution of the number of silhouette pixels [2]. An approach to extracting gait features when given a sequence of images was proposed by Bharti and Gupta which is based on graph of all-pair shortest path distance. Here four feature points namely, ankle, toe, knee and palm, from every frame were selected. These points were considered the nodes of the graph. Node in the first frame connected to that in the third frame, and node in the second frame connected to that in the fourth frame. Weight between two nodes was defined by Euclidean distance. Using this weight, all-pair shortest distance is calculated. Recognition is achieved by matching shortest path distance of input images with the database [5]. More recently, in [1], the authors proposed a method where several ellipses are fitted to different parts of the binarized silhouette of the person and the parameters of these ellipses such as location of its centroid are used as a feature to represent the gait of a person. Template matching is used for recognition. It has been found that camera placement plays a significant role in gait recognition [4].

Chapter 3

Background study on Gait

The science of gait analysis dates back to as early as 1680 when most of the researches were carried out only on animal locomotion. It was only in the 1890s that study of gait of humans was started. Preliminary step in the gait recognition is to study the gait cycle. Gait cycle is defined as the time interval between the same repetitive events of walking. Broadly the cycle is divided into two phases as follows:

1. Stance phase
2. Swing phase

Stance phase is the period when the foot is in contact with the ground whereas swing phase is when it is in air. These two phases are in turn classified into various phases which are illustrated in figure 3.1. The figure shows that the 1st phase starts with

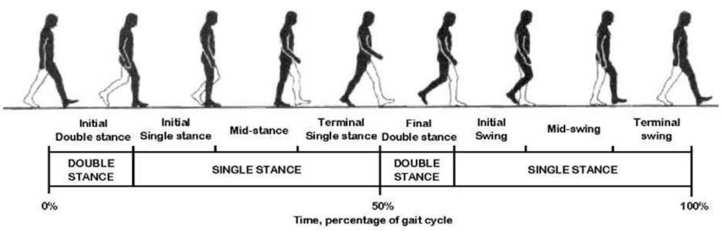

Figure 3.1: Gait cycle

first heel-strike and ends with the opposite toe-off. Then the 2nd phase begins with the opposite toe off and ends with opposite foot strike. The 3rd phase begins with opposite foot strike and ends with toe off. The 4th phase begins when the foot is lifted off the ground and ends when the swinging foot clears the ground and the feet are adjacent. The 5th phase begins with foot clearance where the feet are adjacent and ends when the swinging foot is in front of the body and the tibia is vertical. The 6th which is the last phase begins when the tibia is vertical and ends with initial contact (heel-strike) of the swinging foot. The above description is that of a normal gait cycle and most of the research that has been carried out in this project is on normal gait cycle. But in reality, the gait of a person is affected by many extrinsic, intrinsic, physical, pathological or psychological factors possibly resulting in deviation from the *normal* gait. These factors include terrain on which a person is walking, the kind of footwear and clothing, cargo being carried, height, weight, age and sex of the person, trauma and neurological or musculoskeletal disorders, and personality and emotions of the person. This makes the gait pattern recognition even more difficult but there are certain standard parameters that must be studied for analyzing the gait. Some of these are as follows:

1. Step length
2. Stride length
3. Speed
4. Dynamic base
5. Line of Progression (LOP)

The distance between two toes when a person walks one step is called step length. Stride length is the distance between two successive placements of the same foot. It consists of two steps (left and right). Speed refers to the speed of walking (for example, a significant difference occurs when the person is running). By dynamic base it is meant that the floor is moving, for example in treadmill. When a human walks, its body mass advances through a complex process of joint rotations. This hypothetical path of Center of Mass is called LOP. In this project, the step length has been taken into account to carry out experiment to fulfil the aim of the project.

Chapter 4

Proposed work

We have proposed two algorithms for heel-strike detection. The 1st algorithm is based on the angular variations of limbs when a person walks. Figure 4.1 shows the angle (BAC) to be calculated. The idea behind this proposition is that heel-strike corresponds to the maximum-angle frame. The 2nd algorithm uses a bounding-box approach. In this, the variation in the width of the box helps in determining the heel-strike. The idea is that When the step-length is maximum, the width of the bounding- box is maximum and the frame corresponds to heel-strike.

Angle-based method

Assumption: We assume that a gait cycle starts with one heel-strike(either left or right) and ends when the same heel strikes again. Subject walks at an angle 90° degree to the camera view point.

Step 1: Detect edges using canny edge detection method.

function cannyedge_detection()

begin

load the original image;

find the gray-scale image;

canny edge detection;

end

Figure 4.3 shows the canny image output of figure 4.2. **Step 2:** For determining heel-strike, the $\angle BAC$ as shown in the figure 4.1 is to be calculated in the canny

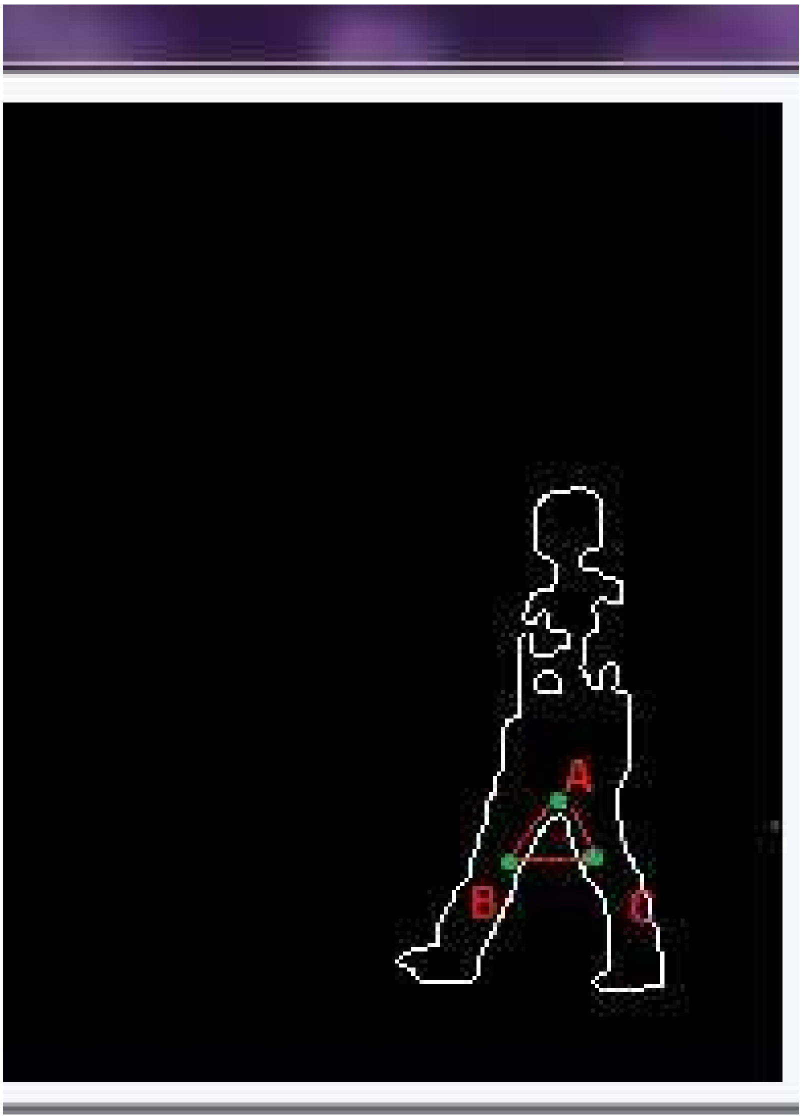

Figure 4.1: Angle to be calculated

image.

To calculate the angle:

(a) Create a data-matrix for canny image.

(b) Process the lower half of the image and determine the row number and column number of points A, B and C.

(c) Determine the lengths AB,BC and CA using Euclidean distance formula.

Figure 4.2: Original image

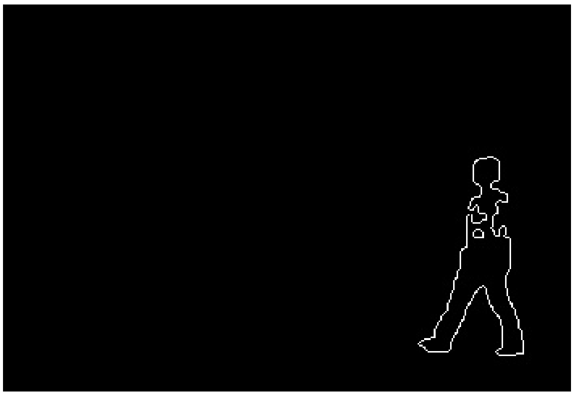

Figure 4.3: Canny image

(d) Use Cosine rule to find the $\angle BAC$:

$$2ab\cos(A) = a^2 + b^2 - c^2 \tag{4.1}$$

where $a = AB$

$b = CA$

$c = BC$

$A = \angle BAC$

Step 3: Load the gait video, capture its frames and find angle in each frame.

Step 4: Frame having the maximum $\angle BAC$ gives the heel-strike.

Short-coming:

This algorithm is view-dependent. It only works well for lateral view, i.e., when the subject walks at an angle 90 degree to the camera. If we run this algorithm for a subject walking at some other angle, say 45°, the angle is not properly observable and difficult to calculate.

Bounding rectangle based method

Assumption: Same assumption as before but subject is viewed from lateral view as well as perspective view.
Step 1: Capture frames from video.
Step 2: Find contours on the frame.
Step 3: Using the contour-image find bounding box in all the frames.
Step 4: Frame having maximum width of the rectangle represents the heel-strike.

Chapter 5

Analysis and results

In the angle-based algorithm, gait cycle started with a heel-strike having $\angle BAC$ equal to 65.8203 units and ended with a heel- strike having angle equals to 62.9225 units. This is shown in figure 5.1. In the bounding rectangle method, we observe

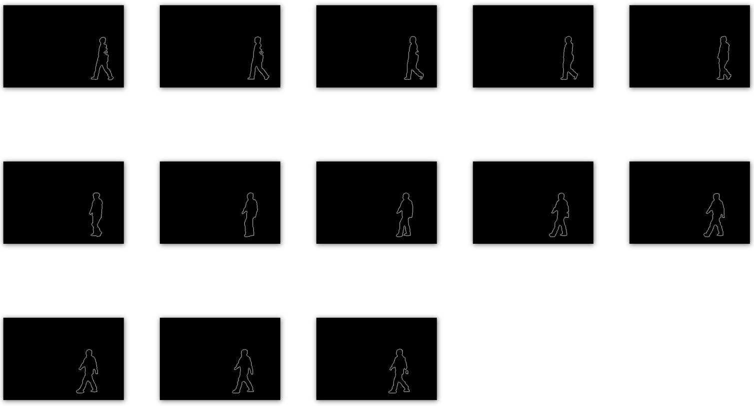

Figure 5.1: Output canny images showing consecutive heel-strikes

the heel-strike by changes in the width of the bounding box as the person walks. The gait cycle started with a frame having step length 65 units and ended with a frame having step length 62 units. This is shown in figure 5.2. As algorithm using bounding rectangle is view independent, the figure 5.3 shows the output frame in 45° angle. Cycle started with a heel-strike having step length 32 units and ended with a heel-strike having step length 31 units.

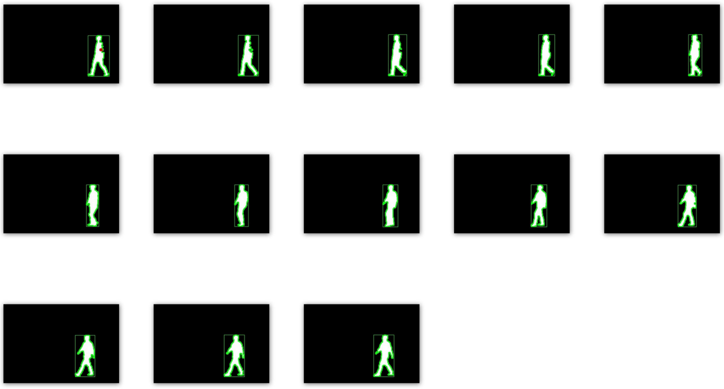

Figure 5.2: Output bounding-rectangle images showing consecutive heel-strikes at 0°

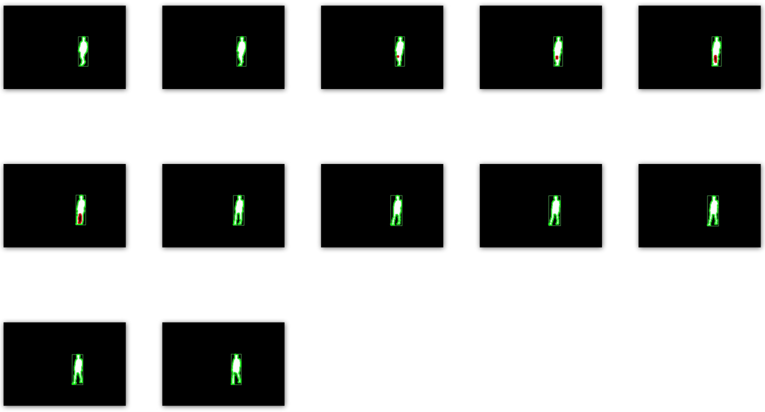

Figure 5.3: Output bounding-rectangle images showing consecutive heel-strikes at 45°

In the figures 5.4, 5.5 and 5.6, frame number with a peak in value corresponds to heel-strike. When subject walks at an angle of 45° to the camera, step length appears to be less when the person is faraway and when the person comes closer the changes are more clearly visible, which can be observed in figure 5.6.

Result was analysed using ground truth. Performance measure taken was standard deviation. This is shown in figures 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6. In both approaches, deviation for ground-truth is 0.73. In angle-based method, for proposed algorithm, deviation is 1.82. In Bounding rectangle-based method at 0°,

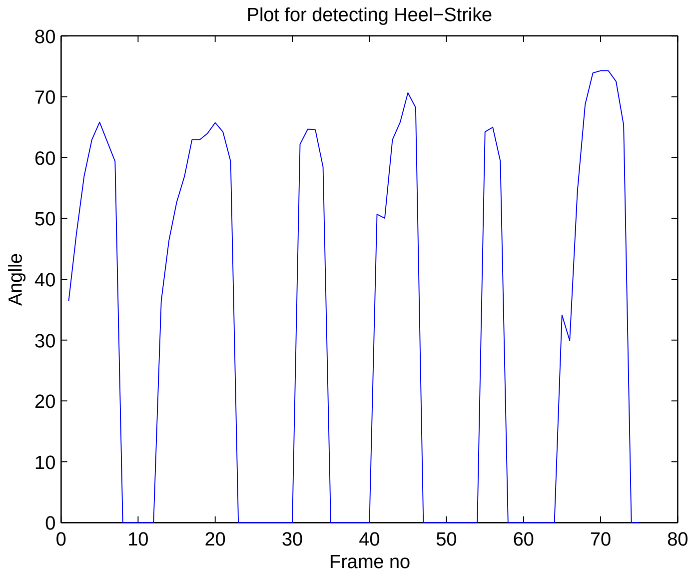

Figure 5.4: Heel-strikes at 0° using angle-based method

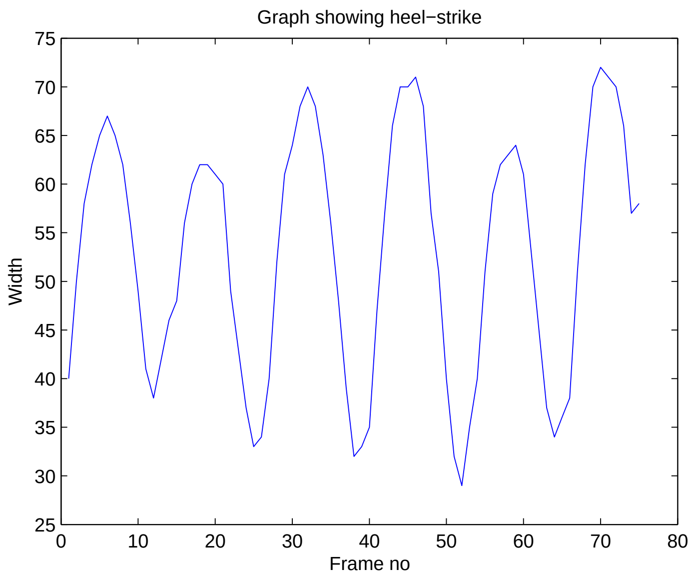

Figure 5.5: Heel-strikes at 0° using bounding rectangle-based method

deviation for proposed algorithm is 1.60. At 45°, deviation for ground truth is 1.57 and for proposed algorithm it is 2.40. From result it is concluded that accuracy is almost same at different view-points in case of bounding rectangle based algorithm. Thus the aim of angle-invariance is accomplished.

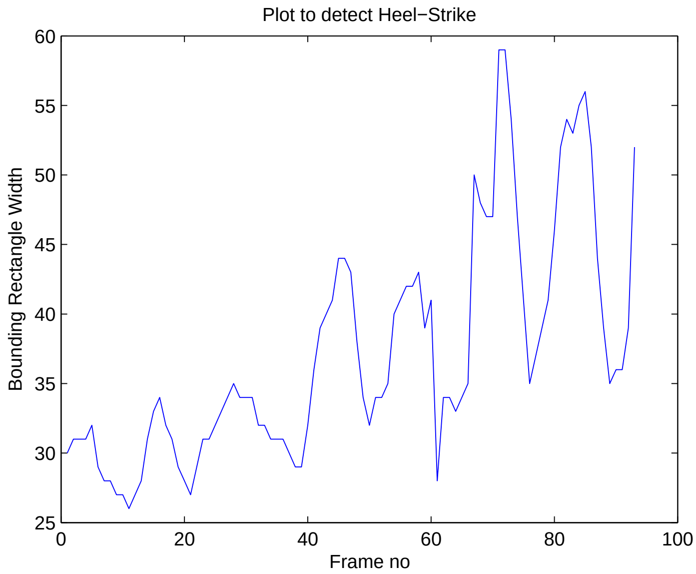

Figure 5.6: Heel-strikes at 45° using bounding rectangle-based method

Table 5.1: Heel-strike frame number for 0°

Ground Truth	5	18	29	42	55	68
Proposed Algorithm	4	19	31	44	55	64

Table 5.2: Difference in consecutive heel-strikes for 0°

Difference in consecutive heel-strikes						Mean	SD
Ground Truth	13	11	13	13	13	12.6	0.73
Proposed Algorithm	15	12	13	11	09	12.0	1.82

Table 5.3: Heel-strike frame number for 0°

Ground Truth	5	18	29	42	55	68
Proposed Algorithm	5	20	31	45	58	69

Table 5.4: Difference in consecutive heel-strikes for 0°

Difference in consecutive heel-strikes						Mean	SD
Ground Truth	13	11	13	13	13	12.6	0.73
Proposed Algorithm	15	11	14	13	11	12.8	1.60

Table 5.5: Heel-strike frame number for 45°

Ground Truth	5	17	30	43	57	67	82
Proposed Algorithm	5	16	28	46	58	72	82

Table 5.6: Difference in consecutive heel-strikes for 45°

Difference in consecutive heel-strikes						Mean	SD	
Ground Truth	12	13	13	14	10	15	12.83	1.57
Proposed Algorithm	11	12	18	12	13	11	12.83	2.40

Chapter 6

Conclusion

In unconstrained views, gait biometrics can be deployed but it is necessary to remove view-point dependence. To achieve this, we can incorporate the inherent periodicity of gait and thus achieve a technique which can correct for the effect of view-point. Here, we obtained an angle in-dependency in the range of $0°$ to $45°$. The experiments that we carried out were in a constrained environment, i.e, it considered the $n$ormal gait cycle. However, the real-life scenario is quite different. Physical factors (injury, pregnancy, drunkenness, fracture) could affect the gait recognition result. Gait of the same individual could change in different stages of life time due to height, weight, bone structure etc.

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