[Resources to help use this Word template to create your thesis can be found at:

[Training in using Word to create a thesis](https://www.southampton.ac.uk/doctoral-college/professional-development-programme/about-the-programme/knowledge-and-techniques-for-research/using-it-software/text-word.page)

Web pages

<http://go.soton.ac.uk/thesispc>

or

<http://go.soton.ac.uk/thesismac>]

**UNIVERSITY OF SOUTHAMPTON**

FACULTY OF [YOUR\_FACULTY (in capitals)]

[Academic\_Unit (underlined)]

Volume [X] of [Y]

[Thesis\_Title (bold)]

by

**[Your\_Name (bold)]**

Thesis for the degree of [name of degree]

[Month\_Year]

**UNIVERSITY OF SOUTHAMPTON**

**ABSTRACT**

FACULTY OF [YOUR\_FACULTY (in capitals)]

[Discipline (underlined)]

Thesis for the degree of [Doctor of Philosophy\_or\_something]

**[THESIS\_TITLE (bold and in capitals)]**

[Your\_Full\_Name e.g. Arthur Francis Jones]

Table of Contents

[Table of Contents iii](#_Toc498004668)

[Table of Tables iii](#_Toc498004669)

[Table of Figures iii](#_Toc498004670)

[List of Accompanying Materials iii](#_Toc498004671)

[Academic Thesis: Declaration Of Authorship iii](#_Toc498004672)

[Acknowledgements iii](#_Toc498004673)

[Definitions and Abbreviations iii](#_Toc498004674)

[Chapter 1 Use the style Heading 1 for chapter titles. There is numbering attached so only use it for chapter titles 3](#_Toc498004675)

[1.1 Use the style Heading 2 for subheadings. This style has numbering attached 3](#_Toc498004676)

[1.1.1 Use the style Heading 3 for the next level of headings. This style has numbering attached. 3](#_Toc498004677)

[1.2 Images 3](#_Toc498004678)

[1.3 Tables 3](#_Toc498004679)

[Chapter 2 Working efficiently 3](#_Toc498004680)

[2.1 Learn useful ways to work with your file 3](#_Toc498004681)

[Chapter 3 A new chapter 3](#_Toc498004682)

[3.1 Adding new sections 3](#_Toc498004683)

[3.2 Cross-referencing 3](#_Toc498004684)

[Chapter 4 Reviewing tools 3](#_Toc498004685)

[4.1 Track changes 3](#_Toc498004686)

[4.2 Spell checker and auto-correct 3](#_Toc498004687)

[Chapter 5 Chapter 5 awaits content 3](#_Toc498004688)

[5.1 Chapter 5 subheading 3](#_Toc498004689)

[Chapter 6 Finishing 3](#_Toc498004690)

[6.1 Printing and PDFs 3](#_Toc498004691)

[Appendix A Your first appendix 3](#_Toc498004692)

[Appendix B Your second appendix 3](#_Toc498004693)

[Glossary of Terms 3](#_Toc498004694)

[List of References 3](#_Toc498004695)

[Bibliography 3](#_Toc498004696)

Table of Tables

**No table of figures entries found.**

Table of Figures

[Figure 1 The Clipboard group in Word 2010 3](#_Toc498004497)

List of Accompanying Materials

Academic Thesis: Declaration Of Authorship

I, [please print name]

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

[title of thesis]

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. [Delete as appropriate] None of this work has been published before submission [or] Parts of this work have been published as: [please list references below]:

Signed:

Date:

Acknowledgements

Definitions and Abbreviations

# Use the style Heading 1 for chapter titles. There is numbering attached so only use it for chapter titles

## Use the style Heading 2 for subheadings. This style has numbering attached

### Use the style Heading 3 for the next level of headings. This style has numbering attached.

Learn about [using Styles](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?7BD2F0D5-EEDA-4431-9C2F-9EF58724B150) to create a well formatted document and get a Table of Contents created by Word based on the Headings you include.

Use the style Normal for your standard paragraphs.

Use the style Quotation for large quotes. This style has indents on the left and right hand side and a slightly larger spacing before them to make them stand out.

Use the style Quotation\_Attribution to show the source of the quote

If you wish to change the default font used throughout the file see [Change the default font](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?19F15C7B-1CC4-4F98-96BF-D6EA1DAF8A09)

## Images

[Insert images](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?866F12E1-A2EC-4177-AD89-D19949D12186) in their own paragraph of Normal formatted text and ‘In line with text’. Images should have a [Caption](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?8B3C0228-F863-4A37-9F68-1CEB3D86375E) inserted

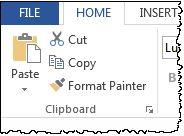


Figure 1.1 The Clipboard group in Word 2010

## Tables

[Tables](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?A9CFD92F-2CD9-4526-8B18-3EE00583BA35) should have a caption and long tables can be made to repeat their title row on multiple pages

# Working efficiently

## Learn useful ways to work with your file

There are lots of time saving ways to speed up working with your file:

[The Navigation Pane](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?922E5D68-7B22-45D7-B58E-7F0BB82EF6BB)

[Browsing and selecting](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?F333358B-B64A-4468-8A94-D662612DC58F)

[Keyboard shortcuts](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?D790044D-A346-4664-8CB7-705C0257124A)

# A new chapter

## Adding new sections

The template has 6 chapters and 2 appendices. Find out how to use [Page Layout](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?A3C076D6-ADAA-44C5-AC9F-C8CFF551A08F) features to add

* New chapters
* New appendices
* Landscaped sections

## Cross-referencing

If you use the heading styles then [cross-referencing](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?257D2144-3CC1-47D0-BE3B-BE1A0888BFBB) to a heading elsewhere is made very easy

# Reviewing tools

## Track changes

Word has useful tools that will allow you to [track changes](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?2167815B-C3D2-4C5A-8BC1-8020A1520D7A) that you might want to make to the file.

## Spell checker and auto-correct

Word has features that will help [check your spelling](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?8DF05004-D415-4320-92B4-24FB460DA31C) – find out how to add words to its dictionary so it can recognise technical terminology that you use.

# Detecting Acceleration for Gait Analysis through Acceleration Flow

## Introduction

In this chapter, we introduce a novel image-based technique to determine the time and position of heel strikes by using our new motion descriptor: *acceleration flow*. Acceleration has been commonly used in physics-based approaches to indicate gait events: [7] and [17] use accelerometers; [18] and [19] use gyroscopes to measure the acceleration (the transition of force in nature) on the subject to determine the gait phases. We note that changes of acceleration can also be determined by analysis of optical flow in image sequences. Standard optical flow algorithms focus on the displacement of brightness values, and do not consider high order motions or classification of different motion types. To address this, we propose an algorithm to classify motion types with in image sequences and subsequently use the extracted acceleration information to detect heel strikes.

Previous standard image-based heel strike detection methods accumulate all silhouettes of the subject and find the areas where candidate points are most dense. They use corner detection [20] and the motion of the head [21] as clues to the heel strikes. Compared with these approaches, our new method only requires three consecutive frames for processing and it also allows near real-time detection with only a single frame of delay.

The technique presented in this chapter is based on the idea of differentiating motion types. Heel strikes incorporate radial acceleration on the foot while walking as they can be detected by changes in angular velocity measured with gyroscopes [7]. In our approach, we first disambiguate acceleration and velocity from optical flow and then decompose the acceleration into tangential and radial components. Experimentation on multiple databases shows that our method reaches state of art accuracy on predicting the timing of heel strikes, as well as demonstrating improved reliability on predicting the positioning of each heel strike within the frame in which it occurs. We first show how acceleration could be used to detect heel strikes by applying a physical quantity to detect gait events based on a computer vision technique. Then we evaluate and explore ramifications of the new analysis.

This chapter is organised as follows: Section 5.2 introduces the gait and heel strike. Section 5.3 describes the methodology of applying acceleration flow to detect heel strikes. The experiments and analysis are presented in Section 5.4. Section 5.5 discusses the current heel strike detection techniques and the advantages and limitation of our algorithm. Finally, Section 5.6 concludes this work.

## Gait, Heel Strike and Previous Techniques

Gait analysis is the systematic study of human walking. It has been mainly applied in two fields: human identification [1] and medical consultation for diseases which affect walking [2]. Current gait analysis techniques can be classified as three types based on the sensor modality that is used to make measurements: physical-sensor based, depth image based and standard image based.

Clinical analysis often uses physical-sensor based techniques to measure physical data from different parts of the walking subject’s body to determine gait events. The main approach is to sense the force level of gait through force sensitive sensors [3], [4]. A popular alternative is kinematic information. One of the most common quantities is the acceleration of the body in two or three dimensions [5], [6]. Rueterbories and *et al.* [7] also use gyroscopes to capture the angular displacement, which is the Coriolis force in nature, to discriminate gait events.

Depth, or RGBD image, based gait analysis techniques have expanded since the introduction and wide availability of PrimeSense and Kinect sensors. These measurements use the distance between the body parts and the sensor in depth images to analyse gait [8], [9]. Lu et al. [10] have built a gait database named ADSC-AWD based on Kinect data.

Standard image-based gait recognition has been extensively studied. Most approaches are targeted at recognition of individual humans, using gait as a biometric signature. The general framework consists of background subtraction, feature extraction and classification [11]. Model-based approaches have an intimate relationship with the human body and its motion, [12] presents an analytical gait model which extract the angle of thigh and lower leg rotation without parameter selection and [13] uses the statistical shape of the body for recognition. Model-free based approaches concentrate on the body shape or the motion of the entire gait process and thus could be used for the analysis of other moving shapes or mammals. Bobick and Davis [14] employ the motion-energy image and motion-history images of silhouette, Han and Bhanu [15] use the gait-energy image for recognition. Model-based methods are view-invariant and scale-invariant but the computation cost is relatively high and the approaches can be very sensitive to image quality. Model-free approaches, an alternative to model-based approaches, are less sensitive to the image quality with lower computation cost though they are not intrinsically robust to variation in viewpoint and scale [11].

|  |
| --- |
| /Users/YanSun/Desktop/Screen Shot 2017-06-28 at 09.15.58.png |
| **Fig. 1** The temporal components contained in a gait cycle and step and stride length during the cycle [27]. |

These gait analysis methods all rely on accurate gait events detection. The components of one gait cycle are shown in Figure 5.1: a *gait cycle* is defined as the interval between two consecutive heel strikes of the same foot. A *heel strike* refers to the moment the heel first strikes the floor. Suppose one gait cycle starts from the heel strike of right foot, the right foot rotates on the heel to touch the floor (‘*stance phase*’) to support the body while the left foot is swinging forward (‘*swing phase*’) until the left heel touches the floor. Then the roles of the two feet switch, the left foot remains flat on the floor whilst the right foot is swinging forward. When the right heel strikes the floor again, then a gait cycle is complete. Hence the accurate and efficient detection of heel strikes is essential because it partitions a walking sequence into cycles composed of stance and swing phases [16]. In addition, the stride and step length can be derived from the stationary position of the heel at the moment of strike.

## Detecting Heel Strike for Gait Analysis by Acceleration

When the heel is approaching to strike, it changes from swinging forward to hit the ground and simultaneously the foot is in a circular motion which is centred at the heel. During this process, a large amount of radial acceleration flow is generated around the foot. The key frame and location of heel strike can be estimated within an image sequence by using the radial acceleration caused by heel strikes as the cue. The framework of our heel strike detection system is illustrated in *Fig. 3.*

|  |
| --- |
| keyFrame.png |
| **Fig. 3** An overview of key frame detection. |

### Locating the frame of heel strike

At the instant of heel strike, the foot hits the ground which forces its velocity to cease in a short time. Therefore, the acceleration of the front foot increases dramatically, due to the disappearance of velocity (rapid deceleration). Also, the striking foot sole’s motion is approximately circular during the period between the heel striking on the ground to fully touching the ground, centred at the heel. Hence, most acceleration caused by heel strikes is radial in nature. The video frames where the heel strikes then can be located by the quantity of radial acceleration. When people are walking, the motion of the body is similar to several joined penduli [27]. Therefore, the radial acceleration caused by a heel strike might be confused with that caused by other limbs since the motion of a pendulum incorporates radial acceleration. To reduce interference, we extract the region of interest (ROI) which is located on the leading foot according to a walking body model. The size of the ROI is where represents the height, shown in *Fig.* *4*.

|  |
| --- |
| Screen%20Shot%202016-06-22%20at%2020.41.47.png |
| Figure 5.1 Gait Proportion[33]. |

At the instant of heel strike, the foot hits the ground which forces its velocity to cease in a short time. Therefore, the acceleration of the front foot increases dramatically, due to the disappearance of velocity (rapid deceleration). Also, the striking foot sole’s motion is approximately circular during the period between the heel striking on the ground to fully touching the ground, centred at the heel. Hence, most acceleration caused by heel strikes is radial in nature. The video frames where the heel strikes then can be located by the quantity of radial acceleration. When people are walking, the motion of the body is similar to several joined penduli [27]. Therefore, the radial acceleration caused by a heel strike might be confused with that caused by other limbs since the motion of a pendulum incorporates radial acceleration. To reduce interference, we extract the region of interest (ROI) which is located on the leading foot according to a walking body model. The size of the ROI is where represents the height, shown in *Fig.* *4*.

### Heel Position Estimation and verification

When the heel strikes, the front foot is performing circular motion centred at the heel. If all the radial accelerations in the ROI are caused by a heel strike, their centres of rotation should all locate at the heel. A dense map of all the rotation centres is derived from the detected radial acceleration in the ROI. The heel strike position is determined by:

where is the density of the rotation centres at point and is the quantity of detected radial acceleration in the ROI.

## Experimental Results

We evaluate our method on three benchmark databases: CASIA [28], [29], SOTON [30] and OU-ISIR [31]. The data used in this paper is collected with various controlled environments. We test around 100 heel strikes in each scenario and the test data incorporates multiple viewing angles and walking directions with gait sequences recorded indoors and outdoors, as described in Table 1. The ground truth of key frames and heel strike positions were manually labelled multiple times by different people. *Fig. 5* shows the variance between different databases for key frames and heel strikes*.* The error in labelling the key frame is generally low and within one frame. In *Fig. 5* *(b)*, the heel strike error shows greater variance on the SOTON dataset as it has the largest detection area.

|  |  |
| --- | --- |
| ../Desktop/frame_errorbar.png  (a) Key frame | ../Desktop/position_errorbar.png  (b) Heel strike position |
| **Fig. 6** Labelling error on different databases. | |

### Key Frame Detection

The key frame (the moment) of a heel strike is detected according to the quantity of radial acceleration in the ROI as described in Section 5.3. The histogram of radial acceleration within a walking sequence shows distinct suggestions for key frames, as shown in *Fig* 3. In the sequence, the radial acceleration appears regularly and noticeably, showing the periodicity of gait. In the sequence illustrated in *Fig*. 3, the heel strikes occur at frame 13, 27, 41, and between frames 54 and 55.

### Heel Strike Position Verification

The ROI extracted according to gait proportions is not always perfectly located on the leading foot in the sequence because the shape of the human body changes during a gait cycle. Also, there is radial acceleration on the other body parts, for example the calf, since the limbs’ motion is that of several joined pendulums [27]. The rotation centres of these erroneous radial accelerations also form invalid heel strike positions. To reduce the effect of this error, the detected key frames are used to filter the heel strike position candidates. When the heel strikes between two frames, the acceleration quantities are used as a weighting factor for deriving the positions. *Fig.* 6 (a) shows detected candidates of heel strike positions and (b) is the result after being filtered by key frames. The (expected) periodicity of gait is evident in the result.

### Detection Performance

Bouchrika proposed a method that accumulated corner positions to determine the positions of heel strikes. Theoretically, there should be dense corners accumulated at the positions of heel since the striking foot does not move for almost half gait cycle during the walking sequence [32]. We compare our detection results against the corner detection method since there are few heel strike detection methods based on standard image sequences with implementation available. Tables 2 and 3 illustrate the comparative results of corner detection and acceleration detection. The results in these tables differ from the earlier results [22] because the background has been included to give a more realistic implementation scenario. The detection of the heel strike moment (the key frame) and position are evaluated separately since they are determined individually and they describe different events in gait analysis. Table 2 shows the F-score of key frame detection and Table 3 is the precision of heel strike positions. Since the corner detection process does not return the key frames, an additional condition is applied which is that for a key frame to be successfully detected a corner position within ±30 pixels from the ground truth is considered as a true positive. For the radial acceleration detector, the criterion for a true positive key frame is whether the detection frame within ±1 frames from the ground truth. For heel positioning results of both methods, a distance within ±10 pixels (along both axes) from the ground truth is considered as an accurate location in Table 3.

In these results, the radial acceleration detector shows a much better ability for precise positioning for all the camera views. It is also able to detect key frames accurately when the camera view is nearly perpendicular to the subjects but the detection rate decreases with the increase of the angle between the camera and the walking subjects. Acceleration is more sensitive to the view angle since the magnitude of the detected acceleration is much smaller than the actual value if the walking trajectory is not perpendicular to the camera. The difference increases with the angle between them therefore a universal threshold becomes inappropriate. *Fig. 7* shows samples of the detection results for different databases. In *Fig. 7* (a), the acceleration detector failed to detect several strikes when the subject was walking away from the camera and the accuracy of localization also decreases with increase in distance and angle between the subject to the camera.

### Robustness of Heel Strike Detection Approaches

|  |  |  |
| --- | --- | --- |
| Dataset | Corner | Acceleration |
|  |  |  |
| CASIA-A (45°) | 75.3 | 40.0 |
| CASIA-A (90°) | 82.9 | 81.2 |
| CASIA-B | 73.3 | 70.8 |
| SOTON | 86.9 | 89.7 |
| OU-ISIR | 65.8 | 73.1 |

|  |  |  |
| --- | --- | --- |
| Dataset | Corner | Acceleration |
|  |  |  |
| CASIA-A (45°) | 25.3 | 72.0 |
| CASIA-A (90°) | 46.6 | 88.9 |
| CASIA-B | 46.2 | 78.8 |
| SOTON | 20.2 | 85.2 |
| OU-ISIR | 12.5 | 82.1 |

|  |
| --- |
| CASIA-A_45R.png  **(a)** CASISA-A (45°) |
| CASIA-A_90.png  **(b)** CASIA-A (90°) |
| CASIA-B_054.png  **(c)** CASIA-B |
| **SOTON_indoorR.png**  **(d)** SOTON |
| **Fig. 7** Examples of detection results with various databases. |

The acceleration decomposition algorithm is based on a subject moving perpendicular to the background so it is theoretically most effective in a direction perpendicular to the camera. Therefore, gait data imaged at multiple views has been used to evaluate the robustness of our approaches to other view angles. The implementation code and heel strike labels are publicly available[[1]](#footnote-1).

The ROI extracted according to gait proportions is not always perfectly located on the leading foot in the sequence because the shape of the human body changes during a gait cycle. Also, there is radial acceleration on the other body parts, for example the calf, since the limbs’ motion is that of several joined pendulums [27]. The rotation centres of these erroneous radial accelerations also form invalid heel strike positions. To reduce the effect of this error, the detected key frames are used to filter the heel strike position candidates. When the heel strikes between two frames, the acceleration quantities are used as a weighting factor for deriving the positions. *Fig.* 5 (a) shows detected candidates of heel strike positions and (b) is the result after being filtered by key frames. The (expected) periodicity of gait is evident in the result.

|  |
| --- |
| ../../Documents/MATLAB/unfilted.png  (a) Candidates for heel strikes |
| ../../Documents/MATLAB/filted.png  (b) Detected heel strikes (after filtering) |
| **Fig. 5** Heel strike verification process. |

## Conclusion

In some forms of gait analysis, it is important to be able to capture when heel strikes occur. In addition, in terms of video analysis of gait, it is important to be able to localise the heel within the frame in which the strike occurs. In this chapter acceleration flow is introduced as a new motion descriptor for detecting heel strikes. The frame of heel strike can be determined by the magnitude of acceleration flow within the frame, and position of the heel strike can be found from the centre of rotation caused by radial acceleration. Our approach has been tested on a number of datasets which were recorded indoors and outdoors with multiple views and walking directions for evaluating the detection rate under various environments. Experiments show the ability of our approach for both temporal detection and spatial positioning. The immunity to three anticipated types of noises in real CCTV footage is also evaluated in our experiments. Our acceleration flow detector is shown to be less sensitive to Gaussian white noise, whilst being effective with images of low-resolution and without incomplete body position information when compared to other techniques.

# Finishing

## Printing and PDFs

There’s even advice on ways to improve you [printing](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?B3BA6016-BA29-4074-8750-ED984008519A) experience and the [PDF](https://guides.soton.ac.uk/uni/isolutions/lg-office-2013/start/default.htm?DE05446D-6E1B-4D7B-9574-4CFF1053550B) version of your file.

1. Your first appendix
2. Your second appendix

Glossary of Terms

List of References

Bibliography

1. https://github.com/YanSunSoton/HeelStrikeAcc. [↑](#footnote-ref-1)