
HUMAN IDENTIFICATION BASED ON GAIT

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 Springer

**HUMAN
IDENTIFICATION
BASED ON GAIT**

International Series on Biometrics

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Preface

It is a great honor to be associated with subjects at their inception. It is certainly early in the cycle for gait – as it is for biometrics. It is then a great honor to be part of the first ever series on biometrics, as it is to be amongst the first researchers in gait as a biometric. It has been great fun too – a challenge indeed since gait concerns not just recognizing objects, but moving objects at that, so we have had to develop new techniques before we saw the first results that people can indeed be recognized by the way they walk.

In terms of setting the scene, and the context of this book with others in the same series, it has been fascinating to see the rise in prominence of biometrics, from what was originally an academic interest, to one that is on the lips of leading politicians. This is because biometrics has the capability to solve current problems of international concern. These essentially center on verification of identity at speed and with assured performance and biometrics has a unique capability here since we carry our own identity. As can be found elsewhere in the series, the earliest biometrics were palm prints – these suited computational facilities available in the 1970's. Then, there has been interest in the more popular biometrics: the fingerprint given its long forensic use; the face given that it is non-invasive and can be captured without a subject's knowledge or interaction; and the iris. Iris recognition has proved quite an inspiration in biometrics, providing some of the largest biometric deployments and with some excellent performance. The fingerprint is now used in products such as mobile phones, computers and access control. Face recognition has a more checkered history, but it is the biometric favored by many in view of its practical advantages. These of course make face recognition more difficult to deploy, as can be found in other volumes in the International Series on Biometrics. Visitors to the US now routinely find their fingerprints and faces recorded at portals of entry. Our context here is to set the scene, not to contrast merit and advantage – that comes later. One of the main reasons for the late entry of gait onto the biometrics stage was not just idea, but also technology. Recognition by gait requires processing sequences of images and this imposes a large computational burden and only the recent advances in speed and memory made gait practicable as a biometric.

Rather than coordinate an edited book, we chose to author this text. We provide a snapshot of all the biometric work in human identification by gait and all major centers for research are indicated in the text. To complete the picture, we have added studies from medicine, psychology and other areas wherein we will find not only justification for the use of gait as a biometric, but also pointers to techniques and to analysis. We have collocated the references at the end of the book, itemized by the area covered and cross referenced to the text. There are of course many other references we could have included since gait is innate to human movement so we have aimed here to provide a set of references which serve as a complete picture of current research in gait for identification, and as pointers to the richer literature to be found in this topic.

As academics, we know well that this book would not have been possible without the contributions of colleagues and students who have conducted research

in this new and fascinating biometric, especially those at the University of Southampton, the CAS Institute of Automation (CASIA) and the University of Maryland. We are very grateful to all whose work appears here. As ever, assembling any book is a difficult task and not eased by current systems. Notwithstanding that, any errors that may have occurred in translating material to this text are our responsibility alone.

Finally, we are grateful to the series editors, Anil Jain and David Zhang for putting the International Series on Biometrics together, and to the staff at Springer who kept us on track. We ourselves have enjoyed working in biometrics and gait very much and we hope that the readers of this text find it not only a useful (and useable!) source of reference, but that it also inspires further interest, development and advances in this fascinating biometric.

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1 Introduction

1.1 Biometrics and Gait

A unique advantage of gait as a biometric is that it offers potential for recognition at a distance or at low resolution or when other biometrics might not be perceivable. Consider an image from a surveillance camera as in Fig. 1.1: the subject's face can be obscured, their hands are at too low a resolution for recognition by shape; it would be pointless even to attempt to recognize subjects by iris or fingerprint pattern. In many scene-of-crime data, the situation is exacerbated by poor quality video data or by poor illumination. In contrast a subject's gait is often readily apparent in an image sequence. Identity can be concealed in a covert way quite easily, one does not assume that every customer entering a bank wearing a scarf over their face is about to rob it. Gait recognition can handle this and might even answer the question as to whether the subject is actually a "him", or whether it is likely that the subject was in fact female.



Figure 1.1 Example Surveillance Video Images

Recognition by gait can be based on the (static) human shape as well as on movement, suggesting a richer recognition cue. It is actually one of the newest biometrics since its development is contemporaneous with new approaches in spatiotemporal image processing and computer vision. These new approaches only started when computer memory and processing speed became sufficient to process sequences of image data with reasonable performance.

Naturally, its development is complemented in other areas. These developments can be used for guidance: the medical analysis of gait can help to guide automated analysis of human condition or to monitor its effects on human gait; work in psychology has already motivated recognition approaches. These developments also offer evidence that supports the notion of gait as a biometric: there is considerable evidence in biomechanics, psychology and literature for the notion that people can be recognized by the way they walk. As such, we have written this book not just to show progress in gait as a biometric: the stock of techniques, the results achieved so far and the insight they provide. We also

describe material from many different areas of potential use in furthering research in this unique and fascinating biometric.

1.2 Contexts

1.2.1 Immigration and Homeland Security

Biometrics has risen to prominence quickly, even with its short history. The current political agendas of many countries are permeated by questions that biometrics might answer, including security and immigration. Now, the U.S. Citizens and Immigration Services require applicants for immigration benefits to be fingerprinted for the purpose of conducting FBI criminal background checks; US-VISIT requires that most foreign visitors traveling to the U.S. on a visa have their two index fingers scanned and a digital face photograph taken to verify their identity at the port of entry. In the Enhanced Border Security and Visa Entry Reform Act of 2002, the U.S. Congress mandated the use of biometrics with U.S. visas. This law required that Embassies and Consulates abroad must issue to international visitors “only machine-readable, tamper-resistant visas and other travel and entry documents that use biometric identifiers,” not later than October 26, 2004. From a topic that was largely on a University research agenda in 2002, biometrics have moved fast.

The move was largely due to performance: biometrics offer a combination of speed and security, ideal in any mass transit scenario. Also, since they are part of a human subject, they are in principle difficult to counterfeit. Not only this, but they are amenable to electronic storage and checking, and devices with such capability continue to proliferate. It is for these reasons that face, iris and fingerprint have found evaluation in security and immigration. Other biometrics have not enjoyed this. This is because some do not lend themselves well to that application scenario, others – like gait – were simply too new to be considered at that time.

1.2.2 Surveillance

In many of the developed countries concern over security is manifest in surveillance systems. These systems are particularly advanced in the UK where on-line face recognition is already in routine use to deter crime. In fact, a high profile case in the UK where a child was abducted and murdered and only the gait of the murderer could be determined from the surveillance data was the inspiration of Southampton’s gait research: as only gait could be perceived was it a valid biometric? A primary aim of surveillance is naturally as a deterrent for criminal acts; much of it is video and it has been used as evidence in courts. The video data can suffer from adverse quality due to poor resolution, time-lapse imagery (images recorded at a frequency much lower than the video sampling rate to save on storage), tape re-use as well as a subject concealing the more conventional biometrics. But it does offer data that gait recognition technology could and is applied to. Some of the difficulties inherent in recording gait

sequences from an arbitrary viewpoint will be shown later. The ongoing trend is that deployment of surveillance systems will continue to increase, suggesting wider deployment of gait recognition techniques.

1.2.3 Human ID at a Distance (HiD) Program

The main single contributor to progress in automatic recognition by gait has been the Defense Advanced Research Projects Agency's (DARPA's) Human ID at a Distance research program led by Dr. Jonathon Phillips from National Institute of Standards in Technology (NIST). This program embraced three main areas: face; gait and new technologies, initially aimed to improve security at US embassies following some terrorist acts in 1998. The Human ID at a Distance program started in 2000 and finished in 2004 (ironically, privacy concerns in the US led to its closure). Gait is a natural contender for recognition at a distance, given its unique capabilities. The DARPA program concentrated on three main areas: face gait and new technologies and in each area there was new technique; new data; and evaluation. The aim of the gait program was essentially to progress from laboratory-based studies on small populations to large scale populations of real world data. Of the current approaches to recognition by gait and data that can be used to analyze performance, those from MIT, Georgia Institute of Technology (GaTech), NIST and the Universities of Maryland (UMD), Southampton (Soton), Carnegie Mellon (CMU) and South Florida (USF) were originally associated with the Human ID at a Distance program. The program achieved many of its initial objectives: gait achieved capability concurrent in research extent and depth with research in face recognition.

1.3 Book Structure

In the next Chapter we shall start by reviewing the evidence for the notion that gait is a biometric: amongst other areas, this arises in medicine, literature and psychology. Not only will we show how gait can be used to identify people, but also derive insight to aid development of automated recognition approaches and analysis. This insight derives from known variation in patterns of gait, including those due to illness and apparel. In biometrics (and pattern recognition in general), capability for recognition is usually evidenced by analysis of performance on specially constructed databases. This allows not only for investigation of performance of a particular technique, but also for comparison of performance with that of other approaches. The selection of existing gait databases is described in Chapter 3 where "early databases" are those which existed prior to the Human ID at a Distance program and the current databases were developed during or after HiD research. We shall then describe the current approaches to gait recognition focusing in particular on techniques and analyses conducted at the Institutions of the authors of this text. In many applications of pattern recognition, approaches with recognition capability are usually based on a corpus of data which is treated either in a holistic manner or which is partitioned by application of prior knowledge. Accordingly we first describe silhouette-based (holistic) approaches which derive recognition capability from the (binary) human silhouette, as

described in Chapter 5. The alternative is to analyze shape and dynamics of the moving human body, usually by deployment of a model, and these approaches are described in Chapter 6. We then describe further application potential for the new biometric approaches before concluding with an analysis of the potential for this new, unique and intriguing biometric. You will find an extensive selection of references on human identification by gait, on gait analysis and on general factors relevant to this new technology. These have been grouped at the end of the book for convenience.

2 Subjects Allied to Gait

2.1 Overview

There is considerable support for the notion that each person's gait is unique. As we shall see, it has been observed in literature that people can be recognized by the way they walk. The same notion has been observed in medicine and biomechanics, though not in the context of biometrics but more as an assertion of individuality. Perhaps driven by these notions, though without reference to them, there has been work in psychology on the human ability to recognize each other by using gait. Those suffering myopia often state that they can use gait as a way of recognizing people. There is other evidence too, which suggests that each person's gait is unique. People have also studied walking from medical and biomechanical perspectives, and this gives insight into how its properties can change which is of general interest in any biometric deployment. We shall start with literature, with definitions of meaning.

2.2 Literature

Perhaps the oldest gait analysis is due to Aristotle [1] though the word "gait" was only to arrive some time later. Its usual meaning is "manner of walking" [2] though this is sometimes given as a "manner of moving on foot" [3] since this can subsume running as well. It is variously given either as derived from *gang* which means gait in German, or from the Middle English *gate* [3], meaning path or gait, as derived from the Old Norse *gata*, meaning path. In this respect it is interesting that one 'English' word for a double is *doppelganger* which derives from "a double" and "goer", the latter given in this case as from middle High German [3].

Shakespeare made several references to the individuality of gait, e.g. in *The Tempest* [Act 4 Scene 1], Ceres observes "*High'st Queen of state, Great Juno comes; I know her by her gait*" even more, in *Twelfth Night* [Act 2 Scene 3] Maria observes of Malviolo "*wherein, by the colour of his beard, the shape of his leg, the manner of his gait, the expressure of his eye, forehead, and complexion, he shall find himself most feelingly personated*" and in *Henry IV Part II* [Act 2, Scene 3] "*To seem like him: so that, in speech, in gait, in diet, in affections of delight, in military rules, humours of blood, he was the mark and glass, copy and book*". Shakespeare's works actually preceded the first complete English dictionary that was only to appear in the 1755, so it is worth checking that Shakespeare's definition accords with our own understanding of the meaning of the word gait. In a curious - but rather expected - circular reference, in Johnson's English dictionary gait was defined [4] to be the manner of walking and Shakespeare was quoted as an exemplar of its meaning. Interestingly, Johnson also suggested it derived from *gat* in Dutch, but the current meaning of *gat* in Dutch concerns an aperture and not gait.