Using the Human Gait for Authentication

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January 30, 2005

Abstract

There are several different methods for biometric authentication. The problem with most of them is that it is relatively easy for an adversary to fake a legitimate user's biometric features. He can steal his fingerprints, his facial image or other features and use it to bypass a secured system.

I will look at a brand new method for biometric authentication which in theory will be very hard to steal; a person's gait — or the way a person walk.

The idea is to collect data using a device small enough to fit on in a person's pocket, which will register the person's walk-features. This data will then be transferred to a computer where it will be analysed to find ways to detect distinctions in different persons walking patterns and use this for authentication.

Sammendrag

Det eksisterer flere ulike metoder for biometrisk autentisering. Problemet med de fleste av dem er at det er relativt lett for en angriper å forfalske en lovlig bruker sine biometriske egenskaper. Han kan stjele fingeravtrykkene, ta bilde av ansiktet eller stjele andre egenskaper som kan benyttes for å slippe gjennom et sikret system.

Jeg skal se på en ny metode for autentisering som i teorien vil være veldig vanskelig å stjele; en persons ganglag — dvs. måten en person går på.

Ideen er å samle inn data vha. en innretning som er liten nok til å ligge i lomma til en person, og denne vil så registrere ganglaget til personen. Dataene vil etter dette overføres til en PC hvor de vil bli analysert for å finne ulikheter mellom to personers ganglag, og dette vil så kunne benyttes til autentisering.

Revision history

Version	Date	Description
1.0.0	4/9-04	Created the introduction chapter.
1.0.1	5/9-04	Modified the introduction chapter and created the LaTeX template.
1.0.2	14/9-04	Added the state-of-the-art chapter and the bibliography.
1.0.3	17/9-04	Added some references to the state-of-the-arts chapter and URL's to the references.
1.1.0	17/10-04	Changed most of the research questions and the state-of-the-arts chapter.
1.1.1	19/10-04	Added a reference to the state-of-the-arts.
1.1.2	21/10-04	Added back an old research question and added some references to the state-of-the-arts and fixed the introduction and contribution chapter.
1.1.3	30/10-04	Added more references and started the work on the methods chapter.
2.0.0	3/11-04	Changed the project topic.
2.0.1	8/11-04	Added some references and some more text to the methods and contribution chapters.
2.0.2	14/11-04	Created the milestones, feasibility, risk and considerations chapters. Added some more referenses to the state-of-the-arts.
2.0.3	17/11-04	Fixed a lot of typing errors.
2.0.3	19/11-04	Added a reference to the state-of-the-arts.
2.0.4	16/12-04	Added some patents to the state-of-the-arts and some other fixes. Removed one of the research questions.
2.0.5	17/12-04	Fixed some misspellings and stuff. Added some more references, some methods for analysis and put on the finished touches.
2.0.6	30/01-05	Added the finnishing touch to this report.

Contents

1 Introduction

1.1 Topic Covered by this Thesis

Biometric authentication has increased in popularity in the resent years, specially after September 11. It involve using the various human biometric features to prove that you are whoever you claim to be. I will look at the possibility of authenticating a person using his gait (i.e. the way the person walk).

Keywords: biometric authentication, gait, data analysis, implementation.

1.2 Problem Description

The problem with more traditional ways of biometric authentication, like fingerprint recognition and face recognition, is that it is relatively easy to fake another person's biometric features (like stealing his fingerprints), and the technology available at the present time is poor at distinguishing an imposter from a legitimate user [1, 2, 3, 4, 5].

1.3 Justification, Motivation and Benefits

It is necessary to discover new ways of authenticating a person which measures features that can't easily be stolen by an imposter. The tracking of a human's movements is in theory much harder for another person to steal than a facial image or a fingerprint, and may therefore be a more effective and better way of securing certain equipment, like cellular phones, PDA's, keys, hand-held weapons or other devices a user wears on his body for a longer or shorted period of time.

1.4 Research Questions

I will look at the following questions:

1. How much work has already been made on this topic?
2. What technology might be used to capture a person's movement?
3. Is it possible to retrieve reliable and valid gait data?
4. Given a set of gait data — is it possible to analyse this data and tell whether or not this data belong to same person?
5. Is it possible to use the human gait to verify a person's identity?

2 Review of State-of-the-Art

I have managed to find some articles and reports on the topic of using gait as a method of authentication, but they are all based on the use of video cameras and different motion capture techniques to identify human beings from a distance. None of the previous work I have found authenticates a person based on data collected from a motion detection device attached to the person, but since the articles might have useful information on gait as a subject, some of them are listed below. The lack of work on the subject of gait authentication using wearable devices, affects this chapter, and some of the research questions from section 1.4 are therefore not mentioned below.

2.1 Gait Related Work

Lee and Gimson wrote an article in 2002 [6] on how to use gait to identify a person, but they captured the person's gait by filming the person and analysing the video, and not using a device the person wore.

The Georgia Tech GVU Centre[1] has a research program where their primary focus is identification of humans from a distance using gait recognition. They have published some work on this area [7, 8, 9], but like with Lee's article [6], the data is not collected from a device the person wears.

Kohle and Merkl at the Institute of Software Technology has written a report [10] where they try to classify different gait patterns. They managed to classify gait data automatically, which was first collected using two ground reaction force measurement platforms.

Morris et al. at Massachusetts Institute of Technology (MIT) has developed a shoe including several different motion-detection sensors capable of collecting data for clinical gait analysis [11, 12, 13]. They have published several video clips of the usage of this shoe on their Web-page[2]. Though this shoe was designed for clinical gait analysis, it is capable of collecting a lot of different gait data, which might be usable for authentication.

Howbray and Nixon [14] describes ways of recognising gait using Fourier descriptors which might be useful when analysing the gait data.

Kuchi et al. [15] describes a database useable for analysing gait data and testing of algorihms. The problem is that this database only consists of image data, and might not be as usable for my research.

Su and Wu [16] has described a method for analysing gait data which uses genetic algorithm neural network, but their study was to detect differences in healthy and pathological gait.

Herrero-Jaraba et al. [17] has described how to use neural networks to analyse gait and recognise humans. It is based on video images, but might still be of use for my research.

[1] http://www.cc.gatech.edu/cpl/projects/hid/

[2] http://www.media.mit.edu/resenv/GaitShoe/

2.2 Motion Capturing Technology

On the 2004 SICE[3] conference, Tahara et al. presented a dynamic human motion simulator consisting of a 3D motion capture system [18]. Though the presentation had nothing to do with authentication or information security, their description of motion capturing might be useful.

Welch describes the principle of motion tracking in his article [19]. It describes the different mechanisms involved in a motion tracking device, but he does not mention gait or how it can be used for authentication.

The Ascension Technology Corporation has a Web-page[4] which provides a lot of information on the latest updates in motion tracking technology and science.

Ganesan describes several different devices used for motion tracking [20], and defines some motion capturing terms and lists some resources to this topic, but the report focuses on motion tracking for Virtual Reality (VR), and not computer security.

Michaelles has written a report [21] on the available technology for physical interactions between mobile devices and humans. The report tries to develop a framework to categorise existing sensors and evaluate their utility in various applications.

Hinckley et al. at Microsoft Research has published a report describing a project where they combined several different interaction techniques into a palm PC device [22]. Among others, they equipped the device with a tilt sensor. Though the techniques was implemented into the palm for user interactions, it might be possible to use similar technology for user authentication. For instance, in their conclusion, they mentions that the device was capable of detecting walking by using a Fast Fourier Transform at 10 Hz with a window of 32 samples.

Schmidt et al. has created a prototype board consisting of eight physical and logical sensors for user interaction [23]. This was connected to a PDA and a mobile phone to determine the usability of such a control environment. The hardware consisted of, among others, two accelerometers for vibration detection. Though the purpose of this project was usability and not security, the method of creating the motion detection equipment can probably be converted into an authentication device.

US Patent & Trademark Office[5] and the European Patent Office[6] has registered some patents which might be relevant to my research. Udilkak et al. has patented an integrated Internet-based orthotic shoe insole [24] used to create a physical reproduction of the manipulated orthotic insole

[3] The Society of Instrument and Control Engineers: `http://www.sice.or.jp/index-e.html`

[4] `http://www.ascension-tech.com/applications/`

[5] `http://www.uspto.gov/patft/index.html`

[6] `http://www.european-patent-office.org/index.en.php`

model, which is subsequently delivered to the user for use as an orthotic insole. Takiguchi et al. has patented a gait detection system [25] using microphones to detect and identify walking pedestrians. Sethuraman and Prem's patent [26] describes different modes for gait recognition systems which might be useful in my research.

Analog Devices[7] is a company that produces several different types of signal processing components. Among others, they produce accelerometers. Their model ADXL202E [27] is a two-axis accelerometer capable of detecting ±2g accelerations, and seems to be suitable for this project. They have also produced an evaluation board [28], which provides a RS-232[8] interface to the accelerometer. It includes software capable of retrieving and storing the data from the device. This might be useful when analysing the data that the accelerometer produces.

A motion capturing device alone is not enough. I will also need some sort of a microcontroller which can collect data from the motion capturing device, store it and send it to a computer when this is needed. Atmel Coorporation[9] is one of the leaders in the manufacturing of microcontrolers. They have produced an evaluation tool, the AVR Butterfly [29] , which will suite my project. Among others it contains a 100 segment LCD display, a 4Mbit dataflash memory, a Real Time Clock 32.768 Hz oscillator, a 4-way joystick with center pushdown button, a RS-232 level converter, a bootloader for programming and a built-in safety pin so it can be hanged on your skirt. All this for a price of USD 19.99[10]. Atmel also provides a free development software, called AVR Studio to program their microcontrollers in the AVR ASM language. In addition, the free software movement has produced a free and powerful C programming utility called WinAVR[11] which will be helpful when programming the microcontroller. All this will therefore be useful tools for this project.

3 Claimed Contributions

As none of the current work I have mentioned in chapter 2 is on wearable methods for gait authentication, my contribution will be in this area. I will try to create a gait detection device, probably consisting of an accelerometer, which sends data to a RS-232 port. I will also create a software prototype which collects data from the gait device and stores it in a database. If this is possible, I will collect gait data from several different persons, and then analyse the data to find methods to detect what data belongs to the same

[7] `www.analog.com`

[8] A standard interface for connecting serial devices.

[9] `www.atmel.com`

[10] `www.digikey.com`

[11] `www.winavr.sourceforge.net`

person. Finally I will detect the FAR and FRR[12] rates for the device, and how useable it is from a user's point of view.

4 Choice of Methods

There are several different approaches to solve the research questions stated in section 1.4. All of them are described closer in [31].

Work on the Topic and Motion Capture Technology The best approach for this project will probably be starting with a literature study on the topics covered by the different research questions. This will give a full answer to the first research question and probably to the second as well.

Retrieving of Gait Data The next step will be to look at ways of connecting a motion capturing device to a computer to collect gait data from the person wearing the device. I will also create a simple program to collect the data from the device and store it in a database for further research. This will solve the third research question.

Analysing Gait Data I will have to use a quantitative analysis of the colclected data using MS Excel or Matlab to find differences in between several persons. This approach should be in a manner that later can be automated to analyse the data. It is then possible to create a prototype of an application capable of collecting and analysing gait data from a person. Since [22] was capable of detecting gait using a Fast Fourier Transformation, this is a method for analysing which I should try. There are also other analysing methods descriced in section 2 which I should try. Other methods usable during data analysis might be discovered as part of the literature study.

Using Gait Data to Verify a Person's Identity After the previous problems has been solved, the task will be to determine whether or not these methods might be used for authentication. This might be done by creating methods for enroling and verifying a person using the device and its software interface. If I get enough time, it might be possible to integrate the gait authentication technology into *NISlab AuthenticationWorkbench*[13] for further study of what FAR and FRR rates such an authentication method will produce. This will also give a reliable impression of how much trouble the usage of the equipment might be from a user's point of view. If there is no time, I can collect the FAR and FRR data manually.

[12]False Acceptance Rate and False Rejection Rate, see [30], page 13.

[13]A software solution created by NISlab to perform user experiments on different types of authentication equipment to detect its FAR and FRR rates.

5 Milestones, Deliverables and Resources

5.1 Milestones

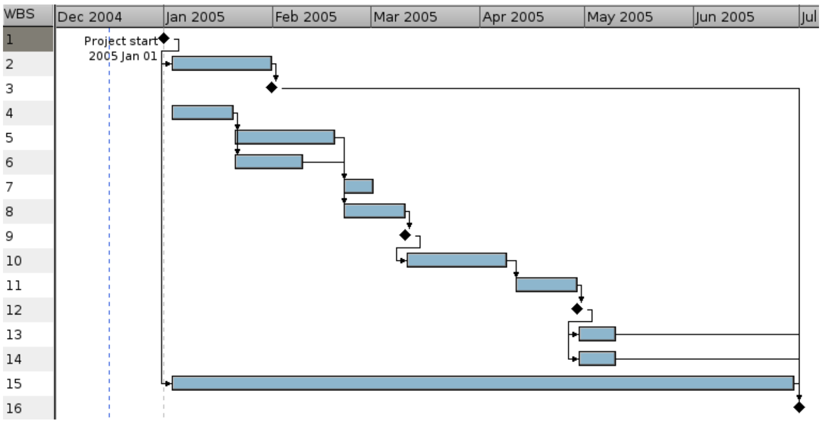

Figure 1: Gantt diagram

I will split the project into several parts as shown in the Gantt diagram in figure 1 and the project tasks in table 1. The execution of the different tasks in the Gantt diagram will be performed in such a way that when the answers to the different research questions from section 1.4 has been answered, a milestone has been reached. I will attempt to get the answers to the questions in the order they are arranged in section 1.4. Since the first two questions merely will be answered as a result of the literature study I will perform in the beginning of the research, they are gathered into one single milestone.

5.2 Deliverables

The deliverables from this research will first of all be a report informing the reader of to what extent the tracking of gait is suitable as an authentication method. The report will also describe what technology could be used when creating devices for gait authentication.

The next result from this research study will be a prototype of a device useable for gait authentication. It will probably consist of an accelerometer either connected to a PDA or connected directly to a computer. This device will send data to a software prototype which will store the data in a database and analyse it to verify the identity of the person using the device.

If I get the time, the gait device will be integrated with Authentication-Workbench, where it is possible to calculate the FAR and FRR rates of the device.

#	**Name**	**Days**
1	*Project start*	
2	Literature study	21 days
3	*Answered the first 2 research questions*	
4	Create gait measuring device	14 days
5	Create gait data collection software	21 days
6	Create gait data storage software	14 days
7	Retrieve reliable and valid gait data	7 days
8	Analyse gait data	14 days
9	*Gait data analyse complete*	
10	Create software for automatic gait data analysis	21 days
11	Integrate the gait authentication utility with AuthenticationWorkbench	14 days
12	*Gait authentication complete*	
13	Find the FAR and FRR for the method	7 days
14	Analyse the method's user friendliness	7 days
15	Write report	128 days
16	*Project finish*	

Table 1: The tasks to perform

5.3 Activities

As seen in table 1, there are 11 different tasks and three milestones which needs to be achieved to complete the project. Some of them requires different research approaches and different time to complete, which I will give a rough estimate of here.

Note that I will begin creating the gait device and start interacting with it as soon as I get my hands on one of these devices, and that the tasks 4 - 8 will elapse more or less parallel with the literature study. Even though it does not show in the Gantt diagram on figure 1, step 4 - 8 will be performed in an incremental process, where I will have to go back and try different equipment, different algorithms and so on if I should be unable to detect distinctions in the collected gait data. Therefore, the estimated time consuming in table 1 is very optimistic, and the activities 11 - 14 will only be performed if there is enough time left. The most important aspect of my study will in the end be to determine whether gait authentication is possible. The user friendliness and FAR/FRR calculations will not be prioritised.

Also note that the length of the different tasks is estimated in *working days*, whereas one working day is estimated to be 8 hours.

5.3.1 Literature Study

This task will be a study of available motion capturing technologies and the science of gait analysis itself to determine how the collecting of gait data should be performed. The study will also five me a better understanding of which methods to use when analysing the gait data. Since I probably will have to use Matlab[14] as part of the process of analysing the gait data, and I don't have any previous experiences with this software, I will have to spend some time of the literature study getting familiar with this software.

In addition to these studies, I will also determine what software and computer systems to use for further research. This includes what programming language to use, what operation system to use and a study of the available standards for biometric authentication, which might be convenient to follow when treating the gait data.

Time Needed: I estimate using 21 days on this task, which can be calculated into 168 hours.

Necessary Equipment: A computer with a network connection, a desk, access to the library and a licence to Matlab and MS Office.

Contributions from Others: Nothing, though I might need to get additional advice from other who has been involved in communicating with gait devices. I might also need advices from people experienced in pattern recognition.

5.3.2 Creating the Gait Device and the Communication Software

This will be the part of the research, where I will depend on assistance from more technical skilled persons to be able to create the gait device, since I don't have any skills in the field of micro electronic design.

When the gait device is created, I will start the programming phase of the research based on the decisions made in the literature study (section 5.3.1).

Time Needed: I estimate using 14 days, or 112 hours on the creation of the gait device. Further, I estimate using 21 days creating the necessary software and 14 days creating the database, which is 168 and 112 hours.

Note that even though this process is estimated to be complete after 21 days, I will probably be adding functionality and removing bugs from the software and database during the entire research process.

[14] A tool for doing numerical computations with matrices and vectors. It can also display information graphically.

Necessary Equipment: First of all, I will need the necessary equipment to create the gait device. This will probably involve an accelerometer connected to a standard communication (RS-232) port, like described in [28], but might also include other technology discovered during the literature study (5.3.1).

I will also need a computer capable of running a database server. This can probably be the same computer I will use to create the software, and must therefore run the preferred operating system. This will probably either be MS Windows XP or a distribution of GNU/Linux. Last, I will also need the necessary software for programming and compiling the gait software.

Contributions from Others: I will need some contribution from other people to be able to complete this task. I will need help to get the components which the gait device will consist of and also to assemble the gait device. This must probably be someone with skills in electronic or micro electronic.

5.3.3 Collect and Analyse Gait Data

When I am in this phase of the project, I should have a gait device to test and some software that communicates with the device. I will now use the device to obtain a set of gait data from myself and several other volunteers. These data will be stored in a database in a form readable for MS Excel and Matlab.

After data has been collected, I will analyse the data using either or both MS Excel and Matlab. The data will be analysed with a quantitative approach such that it is possible to implement into software later in my research process.

Time Needed: I estimate using 7 days collecting data and 14 days analysing the data, which translates into 56 and 112 hours.

Necessary Equipment: I will have to obtain a licence for the Matlab software, but other than that, I only need the equipment from the previous tasks.

Contributions from Others: I will need volunteers when collecting gait data. As this task is part of an incremental research process, I will probably have to collect data from them several times during the process.

5.3.4 Create Software for Gait Analysis

When I reach this phase of the research, I have detected distinctions in individuals gait data, and will create a software which collects and analyses data from individuals automatically. I will have to follow certain rules on how procedures for biometric authentication should be performed. One standard which might be relevant is the *bioAPI* standard[15]. The result of this phase should be a prototype of a software which enrols a person and then verifies the identity of the person using gait data.

Time Needed: I estimate using 21 days, or 168 hours on this task.

Note that even though this process is estimated to be complete after 21 days, I will probably be adding functionality and removing bugs from the software during the entire research process.

Necessary Equipment: Nothing other than the equipment already obtained.

Contributions from Others: Nothing, though I might need more gait data from the volunteers.

5.3.5 Integrate Device with AuthenticationWorkbench

This task and the task described in 5.3.6 will only be performed if I get enough time. I will use the previous created functionality to integrate the gait device into NISlab AuthenticationWorkbench. This will make the process of identifying FAR and FRR rates and the user satisfaction level of the device much easier than if I was supposed to create additional software to get these data.

Time needed: I estimate using 14 days, or 112 hours on this task.

Necessary Equipment: I will need the source code for NISlab AuthenticationWorkbench and a licence for MS Visual Studio .NET.

Contributions from Others: Nothing, though I might need more gait data from the volunteers.

5.3.6 Find FRR, FAR and User Friendliness

I will now have created a prototype for an authentication method using gait data to verify a person's identity. The next task is therefore to detect how well this method works. I will use the NISlab AuthenticationWorkbench to enrol several different persons using the gait authentication device, and then detect the FAR and FRR rates generated when the persons later tries to perform a verification. I will also ask them how well they thought the

[15] `www.bioapi.org`

authentication method worked compared to other authentication methods using either interview or survey.

Time Needed: I estimate using 7 days on the FAR and FRR detection and 7 days on the user friendliness detection, which is 56 hours on each of the two tasks. The tasks will be performed in parallel.

Necessary Equipment: I will need NISlab AuthenticationWorkbench.

Contributions from Others: I will need volunteers to test the authentication method and give their opinion of the user friendliness of the device.

5.3.7 Write Report

This task will be performed during the entire research process parallely with my other tasks whenever there is new data to add to the report.

Time Needed: Since I estimate using 128 days, or 1024 hours on the research process, the report writing is estimated to take this long, though this doesn't mean I will use 1024 fully hours writing the report.

Necessary Equipment: I will need necessary software to write the report, probably the LaTeX-utility.

Contributions from Others: Nothing.

5.3.8 Final Words

As shown in the report section above (section 5.3.7), I estimate using 1024 hours on this research project. This is probably much more than what I actually will spend on the project, since I haven't considered vacations and other occasional days off.

6 Feasibility study

Given the necessary help to create the gait device and the necessary equipment to produce the software, it should be feasible to create software which will obtain gait data in a timely manner. After this is completed, it shouldn't be difficult to collect gait data from different persons in a reliable and valid way. Then comes the analysis of the data — and this is probably the most critical part of the study. I must detect distinctions in different persons' gait data, and this should be performed in a quantitative way such that it is possible to implement the process into a computer software.

Given that it is possible to distinguish different persons' gait data, it should be possible to implement the procedures of detecting these distinctions into computer software, and let a computer do the verification of a person's identity. Note that I will only create a *prototype* of the software. It will probably not be flawless, but give an impression of how such a software would work and — most important — convince the user that it in fact *is* possible to authenticate a person using gait data.

The implementation of the software into NISlab AuthenticationWorkbench should be feasible, since the AuthenticationWorkbench has procedures for adding new authentication devices in a straight-forward way.

The final assessment of detecting the FAR and FRR rates is easy to perform using the AuthenticationWorkbench, but the validity of these data will depend on how many volunteers I get to test the gait device. The same goes for the user friendliness analysis.

7 Risk analysis

The first problem that might occur in this project is not to be able to create the gait device. This could be solved looking for other motion detection solutions, or to get additional help from technical skilled persons.

The second problem is not being able to communicate with the gait device. I consider the probability of this problem to occur low, since the communication probably will be using the RS-232 port, and there are a lot of software available for reading from this port[16].

The major problem of this project is the possibility of finding oneself in a situation where it is impossible to distinguish two persons using the gait data. If I get this problem, one of three possibilities occur; I can either debug the code which is communicating with the device to detect flaws in the software, try other gait recognition technology and devices, or I can change the walking pattern to a way detectable of the device. The first of the possibilities is the best way to start. Hopefully the problem is only a bug in the software. If no bug is found — the best method will be to try new gait devices, but this will also be a serious drawback in the time-schedule. Therefore, if I run out of time, the third possibility involving testing which walking pattern the device detects is probably the best approach.

When the distinctions in the walking pattern is found, the next problem reachable will be that it might be impossible to implement the analysis of the gait data into computer software. I don't consider this likely, since the distinctions in the patterns will be detected using a quantitative approach, which should be an ideal approach for technical science.

The final problem will be if it is no time to implement the authentication device into NISlab AuthenticationWorkbench. This might be as a result of

[16] One monitor is available at the url `http://www.kmint21.com/serial-port-monitor/`

previous problems or bad timing, but if this problem occurs, I will have to use the prototype software already created to analyse the FAR and FRR rates manually. This will give a much less effective way of obtaining the data for analysis, since the process of performing user experiments will be more time-consuming.

As described earlier in this chapter, I might risk spending a lot of time trying to find the right technology and software capable of obtaining gait data which has detectable distinctions from one persons to another. A worst-case scenario would be me stuck in this phase during the entire research process. This will probably result in a MSc report with a slightly different approach than previously planned, as it most likely will describe the problems using gait authentication and not a suggestion on a brand new method for authentication.

8 Ethical and legal considerations

One of the things I must be consider before the project can start is that no-one already has created and copyrighted a gait device like the one I will try to create. This will either limit the research to other gait devices or I must get permission to test the already made gait device to determine how well it works. I have found some patents which are described in section 2.2, but none of them would violate my research.

Another consideration is the storage of privacy information in the database I will create. The Norwegian Privacy Legislation [32] gives some regulations regarding what information to register and how it should be stored, but the main feature of this law is that all persons should have control on what privacy information is registered on themselves. Therefore, all volunteers must know what information I will store during an experiment, and be convinced I will not distribute this information to other.

The last consideration will probably be the ethical considerations regarding the experiments I will be performing when collecting gait data to analyse. The volunteers should participate voluntary and the collected data should be treated confidentially.

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A Revisions in the report

#	Date	Version	Description	Status
1	24/9-04	2.00	Too long problem description	OK
2	24/9-04	2.00	Too extensive research questions	OK
3	24/9-04	2.00	Too inadequate references	OK
4	24/9-04	2.00	Add phone number and e-mail to front page	OK
5	21/10-04	2.00	Define keywords in topic	OK
6	21/10-04	2.00	Describe motivation, research questions and contribution better	OK
7	3/11-04	2.00	Changed the topic	OK
8	16/12-04	2.0.3	Include patents	OK
9	16/12-04	2.0.3	Chang to quantitative	OK
10	16/12-04	2.0.3	Divide the methods chapter after research questions	OK
11	16/12-04	2.0.3	Describe analysis methods	OK
12	16/12-04	2.0.3	Start ordering sensors	OK