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Best Effort Identification

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Acknowledgments

I would like to thank my parents for giving me the opportunity of having a good education, and for always supporting me my entire life, a task which I'm sure was not easy.

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Abstract

This dissertation presents a Best Effort Identification system which provides an identification service of people in the vicinity of a set of sensors. This service is intended to supply applications that create a customized interaction for each client with the needed identification information of this person. Typical approaches to obtain the identification of an individual, mainly based on the filling of forms, are often intrusive and time-consuming, making them unappealing. As such, this system intends to carry out the identification of individuals in a non-intrusive, automatic fashion, collecting available information, avoiding user interaction unless strictly necessary. The main focus of the system, in order to make good identifications, is the correlation of the collected data from the various sensors along with some external data, given their synergy. We expect this approach to facilitate the lives of marketers and improve the overall customer experience when using applications equipped with this system.

Keywords

Identification, Location, Middleware, Event, Sensor, Synergy

Resumo

Esta dissertação apresenta um sistema de identificação "Best Effort" que providencia um serviço de identificação de pessoas na proximidade de um conjunto de sensores. Este serviço irá fornecer informação de identificação de clientes a aplicações que criam interacções personalizadas para cada indivíduo que a utilize. Abordagens típicas para se obter a identificação de um indivíduo consistem, em grande parte, no preenchimento de formulários, sendo muitas vezes intrusivas e um grande desperdício de tempo, o que as torna pouco atractivas. Como tal, este sistema pretende efectuar a identificação dos indivíduos de uma forma automática e não intrusiva, coleccionando a informação disponível, evitando a interacção do utilizador excepto quando estritamente necessário. O foco principal do sistema baseia-se na correlação dos dados recolhidos pelos vários sensores juntamente com alguns dados externos, dada a sua sinergia, de modo a produzir boas identificações. Espera-se que esta abordagem facilite a vida dos comerciantes e melhore a experiência do utilizador, ao utilizar aplicações que façam uso este sistema.

Palavras Chave

Identificação, Localização, Middleware, Evento, Sensor, Sinergia

Contents

List of Figures

List of Acronyms

RSS	Received Signal Strength
PDU	Protocol Data Unit
DOD	Department of Defense
LOS	Line of Sight
AOA	Angle of Arrival
TOA	Time of Arrival
TDOA	Time Difference of Arrival
UWB	Ultra-Wideband
OSN	Online Social Network
SIM	Subscriber Information Module
ICC	Integrated Circuit Card
PIN	Personal Identification Number
PKI	Public-Key Infrastructure
JDBC	Java Database Connectivity
IDE	Integrated Development Environment
ESP	Event Stream Processing
CEP	Event Correlation Engine
OSS	Open-Source Software
EDA	Event Driven Architecture
SQL	Structured Query Language
EPL	Event Processing Language

POJO	Plain Old Java Object
OpenCV	Open Source Computer Vision Library
OS	Operating System
LBPH	Local Binary Patterns Histograms
pteidlib	(Portugal eID Library)
NFC	Near Field Communication
API	Application Programming Interface
XML	Extensible Markup Language

1 Introduction

Contents

In this chapter the problem of identifying and profiling individuals in current context aware systems is introduced as the motivation for the writing of this dissertation. The problem to be solved is also explained, followed by the main contributions of this work.

1.1 Motivation

In current times, almost every piece of information is placed online through several means. With the appearance of social networks, this has become even more evident, and almost everyone uses them. In an age where technology has reached a point that enables information to be gathered and analyzed with relative ease, having an identification of an individual leads to much more information about the subject through searches on the Internet.

Certain applications which serve a vast diversity of goals, such as an online store or a simple clothes shop in the supermarket, require information such as this about the people using them. This information must come from somewhere. The usual approach to this revolves around presenting a series of predefined boring questions to the clients, in the shape of forms, which most people don't have the time or patience to answer.

Given the slow and uninteresting nature of these typical information gathering systems, the need is rising to create something flexible and more advanced to captivate people's attention. A more interesting method would be to create a system which would gather this information in a non-intrusive, automatic fashion, allowing the users to focus on their task instead of wasting time.

1.2 Problem formulation

The work proposed by this dissertation makes use of the technologies and information mentioned above, proposing a middleware that aims to provide a best effort identification service of people around a set of sensors to registered applications, based on the available information. Each sensor will gather particular features of the individual, such as network communications made by their mobile devices through Wi-Fi, an image of their face, the use of an identifying smart card, among others, generating special events containing information about the collected features. Identification will then be inferred from all the information collected given the synergy between the sensors/features - "The whole is greater than the sum of its parts".

This identification is crucial in order to successfully create a profile of a given individual with his personal information. The applications interacting with the middleware may require distinct levels of identification, depending on the functions to be performed. As such, the identification provided might be as loose as to merely classify the individuals as part of a group, or as tight as providing an unequivocal identification for more strict functions, e.g. the payment of a debt.

Since most of the information that this middleware intends to use is already made available by the users, even if indirectly, all that needs to be done is capture the identifying attributes of a given individual in order to make an online search.

After identifying an individual, many things about him can be found, especially through searches in social networks, such as personal information (sex, age, address, work place, etc.) or things that interest them (products, brands, groups, etc.) effectively creating a profile for that individual. This middleware also aims to provide the service to as many people as possible, making use of various sensors for different types of sensing. This will allow for an identification even if an individual does not have the necessary attributes for all the different types of sensors. However, the more information extracted from a single individual, the more accurate the identification will be.

The service provided by this middleware will allow marketers to have more information about their customers, enabling them to provide a better service. Service will improve by, for example, making good suggestions of products the customers might enjoy, given the profiles created by the system. This will facilitate the work of the marketers and will improve the overall experience of the customers, serving them better.

All of the information used by this system is gathered respecting the privacy of the users.

1.3 Main contribution

The main contribution of this dissertation consists on correlating the information generated by the various sensors. The data gathered by each sensor is, by itself, mostly useless given that the level of certainty of discrete events is low. It is the ability to take these pieces and form more complex, more meaningful information that will constitute the core of this work, leading to an adequate identification of the individuals and subsequent association to their personal profiles.

1.4 Dissertation outline

The present dissertation is organized as follows:

Chapter 1 starts by explaining the motivation for this work, followed by the problem to be solved and the main contributions of this dissertation.

Chapter 2 presents the state of the art and related work on the technologies suitable for this master's thesis.

Chapter 3 describes the implemented architecture along with an explanation for each of the implementation decisions.

Chapter 4 gives a more detailed overview of the tools used in the development of this work explaining the reason behind choosing each of them.

Chapter 5 presents some of the experimental results obtained. Results are presented for each of the different sensors, ending with the results gathered from a fully functional system, correlating all of the different events generated by each sensor.

Chapter 6 presents conclusions about this dissertation along with some suggestions for future work.

2 State of the art

Contents

This chapter will reference some of the related work in the area, as well as the current state of the art on the technologies chosen to be used in this work, giving a general understanding of their functionality in order to better introduce them for the future sections of this dissertation.

2.1 Multisensor data fusion

Multisensor data fusion has been an emerging technology for some time now. It had a lot of popularity in Department of Defense (DOD) areas such as automated target recognition, battlefield surveillance, and guidance and control of autonomous vehicles. It was also applied to non-DoD applications such as monitoring of complex machinery, medical diagnosis, and smart buildings. Techniques for multisensor data fusion are drawn from a wide range of areas including artificial intelligence, pattern recognition, statistical estimation, and other areas

Data fusion techniques combine data from multiple sensors, and related information from associated databases or relevant external data to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone. As an analogy, one can think that it might not be possible to assess the quality of an edible substance based solely on the sense of vision or touch, but evaluation of edibility may be achieved using a combination of sight, touch, smell and taste. This is something that has been used by humans and animals, which have evolved the capability to use multiple senses to improve their ability to survive.

While this concept is not new, the emergence of new sensors, advanced processing techniques, and improved processing hardware make real-time fusion of data increasingly possible.

In principle, fusion of multisensor data provides significant advantages over single source data. In addition to the statistical advantage gained by combining same-source data (e.g., obtaining an improved estimate of a physical phenomena via redundant observations), the use of multiple types of sensors may increase the accuracy with which a quantity can be observed and characterized [13].

With the development of the Internet in recent years it has become possible and useful to access many different information systems anywhere in the world to obtain information. While there is much research of the integration of heterogeneous information systems, most commercial systems stop short of the actual integration of available data. Data fusion is the process of fusing multiple records representing the same real-world object into a single, consistent, and clean representation [5].

2.2 Wi-Fi (IEEE 802.11)

Wireless technologies have entered the realms of consumer applications, as well as medical, industrial, public safety, logistics, and transport system along with many other applications.

The main challenge now, in wireless networks, has shifted from speed and capacity to services, where context-aware computing became an emerging paradigm [18]. Context is the knowledge of a user's location, activity, or goals that can be used to filter and modify the way information is presented, its content or even trigger automatic behaviors that benefit the user. With the technical advances in ubiquitous computing and wireless networking, there has been a rising need to capture this context information and feed it into applications.

From the context information available, one of the most interesting features to look at is location. Active Badge [31] is one of the first systems designed for indoor location based on infrared ranging. Since it is necessary to maintain a Line of Sight (LOS) propagation path between the transmitter and the receiver when using infrared signal, objects in-between can easily block the signal and degrade the performance of the system. Active Bat [32] and MIT Cricket [25] came as the successors of Active Badge and are based on the ultrasound technology. The main concern with this technology is that the propagation velocity of the ultrasound is easily affected by the temperature and humidity, which introduce ranging errors over the long term. A system using Ultra-Wideband (UWB) was also presented in the Ubisense localization system [29], which achieves fine-grained indoor localization with good accuracy and precision. However, the cost for a Ubisense UWB reader is currently a lot higher than that of an 802.11 AP.

Indoor radio-location systems consist of two separate hardware components: a signal transmitter and a measuring unit (where most of the system "intelligence" is placed) and can be classified on the signal types (infrared, ultrasound, ultra-wideband, and radio frequency), signal metrics (Angle of Arrival (AOA), Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Received Signal Strength (RSS)), and the metric processing methods (triangulation and scene profiling).

Systems based on AOA, TOA or TDOA have been proposed and have reportedly achieved good precision, however, these measurements necessitate special hardware at either the infrastructure side or the client side which contributes to increase the cost of these solutions and makes its use intrusive. Since RSS measurement is based on a sensory function already available in most 802.11 interfaces, RSS-based indoor localization therefore receives significant attention.

In order to make sense of the measurements collected, most of the location based systems that use the IEEE 802.11 infrastructure, make a scene analysis of the area and use a probabilistic approach in order to predict where an object might be located. This technique uses an adequate representation of an area under observation from a particular point of view in order to identify scene characteristics and thus draw conclusions about the localization of an object inside this area, RSS profiling being one of the most popular methods. This is done in two phases: off-line training and online location determination. The system collects RSS data over a predefined area in the off-line phase. The RSS data is regarded as the observed data, and the positions are considered to be class labels. In the online phase, the real time RSS detected on the mobile user is recorded, and the system is supposed to predict the location of the user based on the RSS [15].

This method has some problems since it requires time to setup, a person needs to walk around an area with a mobile device registering the RSS values and labeling the positions, and is very dependent of the environment since in an indoor environment, RF signal propagation is affected by a number of factors such as multi-path fading, temperature and humidity variations, opening and closing of doors, furniture relocations, and the presence and mobility of human beings [19]. This technique is thus, not scalable to large environments such as enterprise buildings and factory floors because they require extremely cumbersome and intrusive re-calibrations in order to maintain high accuracy in the presence of these changes.

There are also the range-based approaches that collect RSS measurements, estimate the distances between a client and reference points (usually 802.11 APs), and then apply the triangulation method to derive the client location, which takes away some of the effort of creating an area model. This method is somewhat more convenient than scene analysis for applications that merely require the relative location of an individual in the area, rather than its absolute location.

Several systems have been created using the RSS measurement technique to provide localization services to their users. Bahl *et al.* [2] proposed an in-building user location and tracking system - RADAR, which operates by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. The goal of RADAR is to complement the data networking capabilities of RF wireless LANs with accurate user location and tracking capabilities, thereby enhancing the value of such networks and enable location-aware services and applications. RADAR uses the RSS measurements gathered at multiple receiver locations to triangulate the coordinates of the user. Triangulation is done by using both empirically-determined and theoretically-computed RSS information corresponding to a scene analysis of the area of interest.

Horus [36] is another example of a localization system based on RSS measurements. This system works in a similar way as RADAR, but where RADAR uses deterministic techniques to estimate the user location, Horus makes a probabilistic approach, storing information about the signal strength distributions from the access points in the radio-map and using probabilistic inference algorithms to estimate the user location. Horus system analyzes an aspect of the temporal characteristics of the wireless channel: samples correlation from the same access point, showing that the autocorrelation between consecutive samples can be as high as 0.9 and taking this high autocorrelation into account, to achieve better accuracy.

2.3 Facial Detection/Recognition

A facial recognition system is a computer application that allows for an automatic identification or verification of a person from a digital image or video frame from a video source. This is done by comparing the collected facial features from the image with a facial database.

Face recognition systems usually proceed by detecting the face in an image, estimating and normalizing it for translation, scale and in-plane rotation. Given a normalized image, the features are extracted and condensed in a compact face representation which can then be stored in a database or smart card and compared with face representations derived at later times.

Although there are other, extremely reliable methods of biometric personal identification, such as fingerprint analysis and retinal or iris scans, these methods rely on the cooperation of the individuals, whereas an identification system based on analysis of images of the face is often effective without the cooperation or even knowledge of the individuals. It is the nature of this system that makes it appealing for ubiquitous applications.

For a face recognition system to be successfully deployed, it must be fully automatic. A fully automatic system detects and identifies/verifies a face in an image or video sequence without human intervention. Fully automatic face recognition systems generally have two components, detection and recognition. The detection component serves to locate the face area inside an image, allowing its retrieval in order to do some processing. The recognition component identifies or verifies the face [24].

As just mentioned, in order to proceed to face recognition, the first step in this process is to detect the face. In some cooperative systems, face detection is obviated by constraining the user. This however goes against the concept of ubiquity and is therefore, more restraining in the range of applications that can make use of it. This is seen e.g. in common laptops which bring facial recognition software for login purposes, which forces the user to put his head in a specific position in order to be recognized. Most systems, however, do not employ this method, given its inherent problem, using instead, a combination of skin-tone and face texture to determine the location of a face and use an image pyramid to allow faces of varying sizes to be detected. The use of neural networks [26] was one of the first most popular methods to perform facial detection.

The most typical use of this technology is in security systems, such as access to restricted areas and buildings, banks, embassies, military sites, airports, law enforcement. The facial recognition system used by law enforcement to identify people given their mugshots is one of the most commonly known applications of facial recognition [22]. However, recently many more applications have been emerging that make use of this technology such as Google's Picasa digital image organizer[1] that has a built in facial recognition system which associates faces with persons in order to enable queries to be run on pictures to return all pictures with a specific group of people together. Apple iPhoto[2] also includes this technology and lets people tag recognized people on photos and later search them using Spotlight. Facebook[3] also included a facial recognition system in which it would also associate faces to persons and group all the pictures in which an individual would appear, in their profile [23].

[1] GooglePicasa - http://picasa.google.com/
[2] Apple iPhoto - http://www.apple.com/ilife/iphoto/
[3] Facebook - www.facebook.com

Biometric devices normally consist of 3 elements:

- a scanner / reader that captures the user's biometrics characteristics.
- a software that converts this data into digital form and compares it with data previously recorded.
- a database, which stores the biometric data.

The process of identifying an individual using these systems comprises 4 main steps: sample capture, feature extraction, template comparison, and matching. At enrollment, the biometric features of the individual are captured by the scanner. The software converts the biometric input into a template and identifies specific points of data as "match points". The match points are then processed by specific algorithms, into a value that can be compared with biometric data in the database.

Biometric facial recognition systems will measure and analyze the overall structure, shape and proportions of the face: distance between the eyes, nose, mouth, and jaw edges; upper outlines of the eye sockets, the sides of the mouth, the location of the nose and eyes, the area surrounding the cheekbones. [4]

Most approaches are based on a principal components representation of the face image intensities. This representation scheme was first devised for face image compression and subsequently used for recognition. In recognition, eigenfaces [20] are the most commonly used for this type of representation together with a principal component analysis. It's algorithms are explained in [20], [16] respectively. These principal components represent the typical variations seen between faces and provide a concise encapsulation of the appearance of a sample face image, and a basis for its comparison with other face images.

The common approach to face recognition involves the following initialization operations:

1. Acquire an initial set of faces (training set).
2. Create a *face space* with the templates generated from the unique data (features) extracted from the samples.

With the system initialized, new faces may be fed to it, following these steps in order to do recognition:

1. Preprocess the new test images in order to normalize the pictures, making it easier to do recognition - resize to standard resolution, greyscale the image, normalize light and contrast, etc.
2. Calculate the differences (distance) between the test image and the face space.

3. Determine which of the faces in the face space is the most similar to the test image and return the most likely match.

After having processed a face and extracted its features, these are stored and transmitted as a face template. For each representation type, a distance or similarity measure is defined that allows "similar" faces to be determined. This similarity measurement is what correctly discriminates between samples from the same person and samples from different people. As with any biometric system, some threshold on similarity must be chosen above which two face images are deemed to be of the same person. Altering this threshold gives different False Accept and False Rejection rates. Choosing one over the other depends on the level of security required. This is a trade-off against convenience and security: user-friendly matchers have a low false reject rate, while secure matchers have a low false accept rate.

Even though being described here as the best type of biometric identification system, facial recognition is not perfect and still struggles to overcome some obstacles. Problems such as physical changes: facial expression change; aging; personal appearance (make-up, glasses, facial hair, hair style), viewing angle of the face and imaging changes such as lighting variation and camera variations can lead to failures in recognition. A good example of this is the Canadian passport, in which the authorities now only authorize the use of neutral facial expressions in passport photos [27].

Currently, an emerging technique, claimed to achieve improved accuracies, is three-dimensional face recognition. This technique has several advantages over the 2D systems, namely that it is not affected by changes in lighting like other techniques and it can also identify a face from a range of viewing angles, including a profile view. If the collected image is 3D and the database contains 3D images, then matching will take place without any changes being made to the image. However, there is a challenge currently facing databases that are still in 2D images.

2.4 Social Networks: Facebook

"One can say that social is the engine of Web 2.0: many websites evolved into Web applications built around users, letting them create a Web of links between people, to share thoughts, opinions, photos, travel tips, etc" [7].

Social networks are the most relevant change in the use of the World Wide Web, and are often considered the next step in its evolution. Millions of people are creating profiles for themselves, entities, organizations or groups, creating a digital social structure.

Given that social networks represent not only an online socialization platform but also a sort of database of knowledge about each of the users, a new topic comes to mind: information extraction.

In this subsection, Facebook will be addressed given that it is currently the most popular Online

Social Network (OSN) available.

As is well known, Facebook is currently the center of attentions in OSNs, having more than 800 million active users, more than 900 million objects that people interact with (pages, groups, events and community pages) and more than 250 million pictures uploaded per day [33].

The typical Facebook user makes personal information available for everyone to see in their profile. Information such as their full name, address, schools, place of work, date of birth, etc. is shown on their page. Aside from this personal information, all the "likes" a person has made and pictures uploaded are discriminated in their profile. By making friends in Facebook and creating relationships with them or special relationship bonds with family members, Facebook creates an entire network for the given user, showing their friends and even all family members. This enables for quick searches by their friends to find out about their daily activities and current events, but also for third parties seeking to extract information. Add to this the fact that Facebook has and is improving a location based service where people can share their location when they generate a Facebook event, and almost everything about the user is known at any given time.

A face recognition software was also included that allows to associate persons with faces. This feature was presented to users as an option to tag their friends in pictures, to give the option of later another friend reaching the profile of that individual just by having access to the picture. This tagging feature, although liked by many, was seen as a grave privacy breach by others.

Facebook has been fighting several law suits over their facial recognition software which allows the identification of individuals from pictures. Not only this, but the technology can also help third parties locate the social security numbers of Facebook users, just from the information on their Facebook profiles and their photo. This is an harmful example, but exemplifies the potential of information extraction from social networks. *"About 90% of Facebook users use their real identities on the network. If you combine this fact with another, i.e., that the vast majority also use frontal face photos of themselves as their primary profile photos (which, by the way, Facebook makes visible to all by default), you end up with the concept of a de facto Real ID"* [12].

It is the fact that a Real ID can be attained from a profile photo combined with the possibility to extract this information that makes Facebook an interesting tool to look at in terms of using it as an identification service.

The task of extracting and analyzing data from OSNs has attracted the interest of many researchers. These networks are a very interesting topic to many, since a complete study of the structure of large real communities were impossible or at the very least expensive before, and the ability to discover real-life relationships, often hardly identifiable. In order to make these studies, it is necessary to develop the tools to acquire and analyze the data from very large OSNs. It was estimated in 2010 that the crawling overhead required to collect the entire Facebook graph would be 44 Terabytes of data [11]. Various different techniques were developed to crawl large social networks and collect data from them. Various algorithms were created by third parties that took into consideration factors like: *Node Similarity Detection*, *Community Detection*, *Influential User Detection*, etc. The major goal of these efforts is best described by Kleinberg [17]: *"topological properties of graphs may be reliable indicators of human behaviors"*. Most of the developed techniques based themselves in crawling the front-end of websites, given that the OSNs datasets are not usually publicly accessible, data is stored in back-end databases that are only accessible through the Web interface [10]. The typical approach for crawling these websites for information was carried out by utilizing search algorithms such as Breadth-First Search or Random Walk such as used by Gjoka et al. However, some problems appear to those seeking to mine information from Facebook, in the form of user privacy. These restrictions make it harder to extract information through the conventional crawling methods. More recently, in order to facilitate the work of developers, Facebook made available a tool by the name of "Graph Application Programming Interface (API)" [34] which presents a simple, consistent view of the Facebook social graph, uniformly representing objects in the graph (e.g., people, photos, events, and pages) and the connections between them (e.g., friend relationships, shared content, and photo tags). From a business perspective, this tool would *"give marketers new ways to make sense of a user's preferences, passions and connections, which are the 'objects' of their lives."* [37].

2.5 Smart Card

This section will provide an overview of the current state of the art in Smart Cards. Its main benefits, utilities and characteristics will be described.

By definition, a Smart Card is an electronic device that can participate in an automated electronic transaction, with security, and is not easily forged or copied. This is mainly what distinguishes a Smart Card from the regular magnetic stripe cards, since these do not have processing power and can easily be copied or forged.

Smart cards can be seen as many different things: microcomputer card, electronic purse, train ticket, Subscriber Information Module (SIM) card for mobile phones, etc.

Smart cards were invented due to the difficulties posed by the expensive telecommunications required for the much cheaper magnetic-stripe technology. Because any individual with access to the appropriate device can read, rewrite or delete data on a magnetic-stripe card, such cards are unsuitable for storing sensitive data. As such, they require extensive online, centralized, back-end infrastructures for verification and processing. Given the costs and problems derived from establishing these infrastructures, an alternative which could operate securely offline was sought. Starting with concept definition in the early 1960s and following patents in 1968, developers made huge improvements over magnetic-stripe technology introducing the Integrated Circuit Card (ICC), also dubbed the "smart card" or "chip card". As significant progress was made in cryptography during the 1960s, smart cards proved an ideal medium for safely storing cryptographic keys and algorithms of the type needed in bank cards. [14]

The three core functions of smart cards are:

- Information storage and management
- Identification of the card holder
- Calculation (especially for encryption/decryption)

These functions lead to a large variety of uses, having authentication, portable personality, portable data files, data transport and stored value, as the five most popular ones. Given the nature of this master's thesis, more emphasis will be given to the authentication feature, since smart cards offer good means of identifying an individual. Usually this is based on a user name and a password or Personal Identification Number (PIN), but other authentication methods are already available or under test, such as biometrics. Fingerprint scanning along with smart identity cards is in routine use already in some countries and retinal scanning is widely used for military access control.

From a consumer marketer perspective, online commerce represents great opportunities for growth and profit. But it also poses new challenges, primarily in terms of authentication and non-repudiation for the prevention of fraud.

The smart cards with Public-Key Infrastructure (PKI) capabilities allow consumers to attach digital signatures to online transactions they make. Technologies such as cryptography make it virtually impossible to forge or alter these signatures. This means that a strong identification of the individual is provided and the consumer marketers know precisely with whom they are conducting business. Moreover, an anti-fraud system is also provided because a cardholder cannot deny or repudiate a transaction verified by a digital signature. These features add motivation for the use of the technology in order to create safe and easy online commerce [6]..

Smart cards are also a very portable technology enabling their users to access privileges virtually anywhere. They will be able to insert their cards into computers, telephones or terminals that are equipped with smart card readers, turning a generic device into a highly personalized one.

In order to assure interoperability between different Smart Cards and the terminals, standards were created, defining the proper ways to communicate with the cards as detailed in [8].

The citizen card[4] is a very good and relevant example of a smart card used for authentication purposes.

[4]CartaoCidadao - http://www.cartaodecidadao.pt/

3 Architecture

Contents

This chapter will cover the architecture of the developed system starting by presenting the overall system design followed by the system requirements. The development environment and external tools used are also presented here.

3.1 Overall system design

This section presents the overall system design chosen for the development of the present work.

The system created here acts a middleware, serving applications that have registered in the system. These applications expect to receive information about people inside certain areas of interest, allowing some personalized action or information to be presented to that person. As such, the main focus of this work resides on the identification of individuals that enter these areas of interest which consist of the coverage area of a set of sensors. These sensors could be of many different types, but what is important is that each of the sensors is capable of sensing a particular set of data. Relevant data is defined as the personal characteristics of each individual, which may come from different sources, but all have something that is specific to that user and adds knowledge to the system. This relevant data is not only comprised of identifying attributes of the individual, but also information that is somehow connected to this person, which serves to create a user profile. After an identification is made, all information about that given individual is sent to the registered applications.

3.1.1 System requirements

For the system to be able to provide good quality of service for the users, a set of system requirements must be ensured.

1. The identification of the individuals should be as non-intrusive as possible, i.e. the interaction between the user and the sensors should be as little as possible and adequate to the level of identification requirement.

2. The system should try to identify as many people as possible, relating information gathered from the various sensors in order to gain more information.

3. Identification must be made in a time window that makes sense to the business logic.

4. Disclosure of private information should be explicitly controlled by the users.

3.1.2 The sensors

In this architecture, four different types of sensor were implemented. They are: Wi-Fi sensor for mobile devices; Smart card sensor; Biometric sensor (Kinect) for facial recognition; Social network (Facebook) sensor. Each of these sensors will collect specific kinds of data and were chosen considering that simplicity and ubiquity was desired.

- The Wi-Fi sensor will scan for the periodic communications made by Wi-Fi devices. Wi-Fi capable mobile devices are something which is nowadays used by everyone and their Wi-Fi communications contain some powerful data, such as a unique identifier and location information.
- The smart card sensor will make use of identifying smart cards in order to retrieve as much information as possible, by accessing the card's data. These smart cards are small, very portable items, packed with important and useful features, namely authentication and the storage of personal data. Looking at citizen cards, which nowadays are also smart cards, this becomes another item which is also used by everyone.
- Facial recognition is an identification technique which is performed over images of an individual's face, which by using the biometric sensor, can be captured easily and analyzed. Again, this is usable by everyone, as long as a non-obstructed face is presented.
- Finally, the social network sensor will complement the profile of an individual with his publicly available information on this person's Facebook page. The choice of the social network was obvious, since it is the current number one social network in the world, and the number of people using it is very large and is continuing to rise.

As can be seen, each of the sensors is equipped with very distinct sensory capabilities. They will capture different types of data in very different ways and it is important that each of the sensors performs well to guarantee a smooth operation of the overall system. One of the most important parts for this is the collection and management of the available data. As was just mentioned, each of the sensors operates in a very specific way and the data each one collects is unique, however, in order for the system to function correctly, the data must be analyzed properly by a common unit to every sensor, which can process the information from each of them and make sense of it as a whole. Therefore, when one of the sensors captures meaningful data, it must be able to send it to the system, and this is done in the form of an event. The information captured by the sensors is encapsulated in events and sent to an event management unit, which is programmed to receive them and take some sort of action upon them.

The events generated by these sensors will be correlated by the event manager which consumes them, stores them and generates new events. By storing information the event manager will enrich its knowledge, thus allowing for the generation of more complex events. One of the relevant aspects for the effective correlation of the events is the combination of localization and timing. The sensors will, as best as possible, tag all the events generated with the spatial-temporal location of the individual that originated it. This feature will effectively allow the middleware to decide that several events generated in the same spatial-temporal area, relate to the same individual.

The type of correlation between events is configured in order to provide a high-level interface for the specification of the business logic. As such, a generic event manager was used, programmed through a specific high-level language, in this case, Java.

3.1.3 Confidence levels of identification

One of the most important characteristics of this system is the fact that it deals with a lot of uncertainty. Each of the sensors chosen have a specific margin for error which must be taken into account in order to produce good results. As the title of this dissertation suggests, the system operates on a best effort premise, and as such, most of the times, the information generated will not be 100% accurate. The most challenging aspect of this work is precisely dealing with these uncertainties in such a way, that by looking at several events generated from different sources, more information can be inferred, producing better results even if the original pieces of information were not very reliable. A case where this can be easily demonstrated is when capturing Wi-Fi information in the coverage area. Even if the Wi-Fi sensor is working perfectly and generating extremely accurate information, the information itself is mostly useless. The applications registered in the system would have no use for information about a random Wi-Fi capable device in the coverage area. The same happens with facial recognition, as an image of a face alone also means nothing. It is the fact that this information can be correlated that makes this work interesting and worthwhile for the registered applications, e.g. if the Wi-Fi information previously captured could be associated with an individual, this would provide an accurate identification in future visits by this person. Also, if the previously captured face image could be matched against a training facial database which contained sample images of registered clients, an identification could be performed with that face image.

After such associations are made, the system has much better means of identifying individuals in the area. This identification can come from an event generated by a single sensor, given a correct association to this type of sensor had been done previously. But again, each sensor has a specific error margin, which means that identifications made from different sensors would have distinct accuracy. To manage this, each identification made has its own confidence level corresponding to which and how many sensors participated in that identification.

3.1.4 Development environment

This section presents the environment in which the system was developed. Figure 3.1 illustrates the network topology used.

As shown in figure 3.1, this work was developed on three different machines.

This topology was chosen, taking into account that at least two different machines were needed to work as Wi-Fi sensors. As will be explained in more detail in the respective section, the Wi-Fi sensors communicate with each other, to determine which mobile devices are in

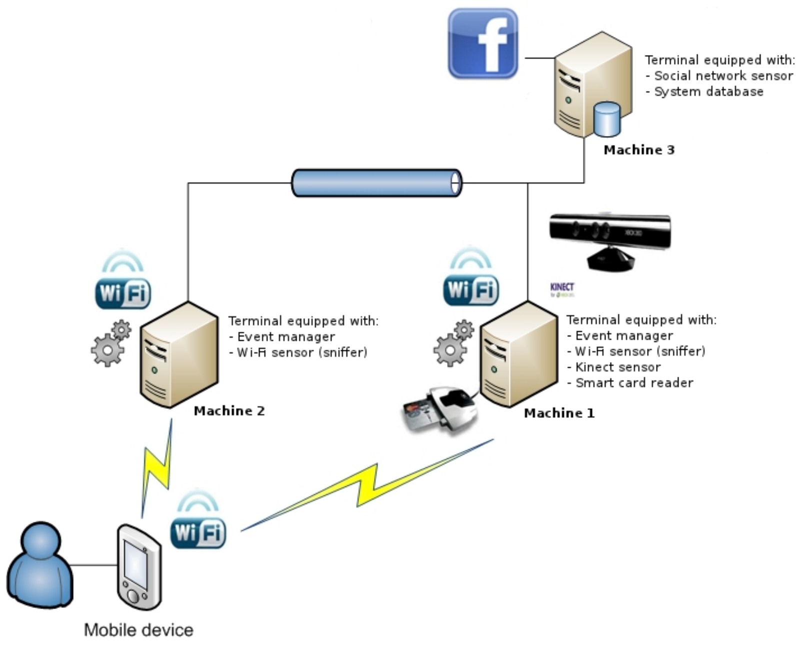


Figure 3.1: Network topology of the developed system.

both sensors' coverage area. As such, machine 1 and 2 are both equipped with a Wi-Fi sensor. Machine 1 holds most of the remaining sensors, the biometric sensor and the smart card sensor. Both these sensors make sense to be placed in the same machine since useful information can be obtained this way, such as capturing face images of the person using the smart card. Machine 3 was chosen to carry the part of the work corresponding to the social network sensor and the system's database. This machine also had the advantage of being one of the machines in campus available to students, which allowed external connections to the network. With this feature, many more tests could be made, having many different people use the social network sensor from their homes. The choice of placement of the database here was made because this is a machine operating all day, every day, accessable by the remaining machines in the system, and is well managed.

Machines 1 and 2 were running the Linux Ubuntu operating system version 11.04, and machine 3 had Debian 6.0.5. Most of the programming done for this work was written in Java with the assistance of external Linux programs. HTML and PHP were also used for web development, Python and C++ for programming some of the face recognition functions, and MySQL to create the system database along with Java Database Connectivity (JDBC) to access it using Java. The entire development was made using Eclipse, a multi-language software development environment comprising an Integrated Development Environment (IDE) and an extensible plug-in system. The specific libraries and external programs used are referenced and explained in their respective sections.

3.2 Architecture tools

In the development of this dissertation, some external tools were used to perform some of the core functionalities of the work. This section presents those tools along with the reasons that motivated their choice.

3.2.1 Event manager

As has been mentioned along this dissertation, the implemented system makes use of several sensors, each capable of sensing a different type of feature. These sensors are constantly collecting data and need to feed it to the system in order to make sense of it. As such, each of the sensors will generate an event when meaningful data is captured and feed it to applications or services which generate new events on their turn. To provide this feature, an event management unit was chosen in order to correlate events generated by the various sensors. This will allow the system to generate more complex and meaningful events, leading to more information and a better identification of a person.

"Information is critical to make wise decisions. This is true in real life but also in computing. Information flows in from different sources in the form of messages or events, giving a hint on the state at a given time" [9]. That said, looking at discrete events is most of the time meaningless. The system needs to look at the events received possibly combined with other information to make the best identification at the right time. The software required to work with these events is Esper[1], an open source Event Stream Processing (ESP) and Event Correlation Engine (CEP) written in Java.

While there are other solutions for managing complex event processing, such as: Oracle CEP[2], SQLStream[3], IBM WebSphere[4], ActiveInsight[5], among others, Esper was chosen taking into consideration that it is Open-Source Software (OSS), well-documented, designed specifically for real-time architectures, and written in Java, providing an easy programming interface and is suitable for integration into any Java process.

Esper enables rapid development of applications that process large volumes of incoming messages or events. It filters and analyzes events in various ways, and responds to conditions of interest in real-time.

While discrete events when looked one by one might be meaningless, event streams, i.e. that is a continuous set of events, considered over various factors, such as time or location of occurrence, and further correlated, are highly meaningful, providing the applications using the middleware with enough information to take decisive action.

[1] Esper - http://esper.codehaus.org/
[2] Oracle CEP - http://www.oracle.com/technetwork/middleware/complex-event-processing/overview/
[3] SQLStream - http://www.sqlstream.com/
[4] WebSphere - http://www-01.ibm.com/software/websphere/
[5] ActiveInsight - http://www.activeinsight.org/

Targeted to real-time Event Driven Architecture (EDA), Esper basically instead of working as a database where data is stored to later poll it using Structured Query Language (SQL) queries, Esper works as a real time engine that triggers actions when event conditions occur among event streams. A tailored Event Processing Language (EPL) allows registering queries in the engine, using Java objects (Plain Old Java Object (POJO), JavaBean) to represent events. A listener class - which is basically also a POJO - will then be called by the engine when the EPL condition is matched as events come in. The EPL allows expressing complex matching conditions that include temporal windows, and join different event streams, as well as filter and sort them.

The Esper engine provides a high abstraction and can be thought of as a database turned upside-down: instead of storing the data and running queries against stored data, Esper allows applications to store queries and run the data through. Response from the Esper engine is real-time when conditions occur that match user defined queries. The execution model is thus continuous rather than only when a query is submitted.

3.2.2 Kinect

The Kinect is a motion sensing input device by Microsoft for the Xbox 360 video game console. Based around a webcam-style add-on peripheral for the Xbox 360 console, it enables users to control and interact with the Xbox 360 without the need to touch a game controller, through a natural user interface using gestures and spoken commands [21].

The Kinect is equipped with two cameras, one RGB, for face recognition and display video, and one infrared, for tracking movement and depth. Although this is a proprietary product of Microsoft, open-source drivers for the Kinect are being made available, which are interesting in the scope of this dissertation, mainly to perform face detection and recognition.

In the work developed, the Kinect will be used since it has great potential in the fields of motion tracking and facial recognition. It will make use of a biometric trait that every person (in normal conditions) has, a face, and provide the middleware with an identifying feature of the individuals, enabling the search for these people in social networks, given the captured face.

The way the optical system works, on a hardware level, is fairly basic. An infrared laser is projected into the room and the sensor is able to detect what is going on based on what is reflected back at it. Together, the projector and sensor create a depth map. The regular video camera is placed at a specific distance from the 3D part of the optical system in a precise alignment, so that the Kinect can blend together the depth map and RGB picture [35].

The regular camera does the traditional camera work, while the infrared light sensor measures depth, position and motion. The RGB camera needs light while the other does not. Facial recognition uses both.

The infrared camera will allow the system to know when an individual has stepped in front of the camera, using the motion detector. By measuring depth, the Kinect is able to determine if the individual is close or far away, in order to decide if it is necessary to take action or not, depending on the requirements of the application. By combining the RGB camera captures with the depth map, it is possible to detect the face of the individual, the distance it is at, and afterwards, attempt face recognition using the collected facial features.

4 Implementation

Contents

After presenting the system architecture, this chapter will provide the implementation details for each of the relevant parts of the system.

4.1 Social network sensor

The first sensor presented is the social network sensor. Facebook was used for this part of the work as it is currently the most popular social network around, contains a lot of useful information, is very easy to use, and offers several important development tools through its Graph API. It consists of a big network of people which have their own profiles available online, filled with as much personal information as the user chooses to upload. A system such as the one presented in this dissertation has a lot of use for information such as this in order to profile and identify individuals.

Since the system requires a registration from the users in order to identify them, the privacy and registration choices implemented are described.

4.1.1 Privacy & Registration

In order to protect the privacy of the individuals in the system's coverage area, personal information will only be gathered and used if the individual is already a registered client in the system. To provide this feature, a small registration step is required, having the user simply do a Facebook login on the system's Facebook page. This page was created with simple HTML and PHP in order to interact with Facebook's Graph API, and placed online as an *App* on Facebook. Having the page be seen as an *App* by Facebook, enables special developer functionalities which proved useful as will be explained here. At the time of the login, the user is presented with an information disclosure agreement, which, if accepted, successfully registers the new client in the system. This registration method was chosen taking into account the fact that people do not want to waste their time with boring registrations, and that the login feature in Facebook is fast, simple to use and is known to everyone using this social network. The (customizable) disclosure agreement is one of the many useful features of Facebook's *Apps*.

When a new client is registered, some more steps are taken by the server managing these requests. If the information disclosure agreement is accepted, all information from the user is pulled from Facebook by the system and stored in a database. Information such as:

- Facebook id
- Facebook link
- Profile picture
- Email

- Name
- Birth date
- Gender
- Hometown
- Workplaces
- Relationship status
- Likes

The items presented here are not the only ones which can be collected from Facebook, more can be obtained for other uses, however, for the work developed here, these were the attributes used. As can be seen, a lot of information can easily be obtained from a social network, and all that was needed were two simple clicks from the user. By having the user agree to the information disclosure agreement, the system is able to bypass the privacy barriers imposed on the user's profile by Facebook, which is often only visible by their close friends. This is done by using Facebook's Graph API.

4.1.2 Graph API

"At Facebook's core is the social graph; people and the connections they have to everything they care about. The Graph API presents a simple, consistent view of the Facebook social graph, uniformly representing objects in the graph (e.g., people, photos, events, and pages) and the connections between them (e.g., friend relationships, shared content, and photo tags)." [34].

This API allows developers to access many different functions, namely, information extraction. To be able to access these functions and start pulling information from a user's profile, the system's Facebook *app* requires an "access token" which is generated the moment the user accepts the privacy agreement. This access token is also stored in the database, together with the user's personal information, allowing for future accesses when they are required. Without this token, Facebook would reject all attempts of pulling information from a user's profile, except the public information. Out of the different types of tokens, the long-term access token was chosen, to provide the system with the longest access time (60 days). Further user visits to the system's page will also refresh the access token which enables virtually endless access as long as the user is interested in using the system.

In order to keep the clients' information fresh, every time the system triggers an event which corresponds to an identification of a user, the user's information is pulled from Facebook once more, updating the database.

If, for some reason a client no longer wishes to be part of this identification system, all that needs to be done is remove the access control corresponding to the application from his Facebook profile, actively revoking the access token, making further attempts to pull information fail.

From the attributes collected, the most relevant ones for identification are the name, birth date and profile picture. These are the attributes that are checked when trying to associate Smart Card data with a client's profile (more detailed in the Smart Card sensor section), where the name is compared, followed by the birth date, and if there is still some ambiguity after these two verifications, facial recognition is also performed, trying to match the facial picture in the card with the profile picture from Facebook. This association assumes that the client uses a Facebook profile picture of himself containing a frontal view of his face, the name used in the profile also corresponds to his real name (at least the first and last name, case and accentuation do not need to match) and the birth date given is either empty (some people don't like to divulge this information in social networks) or the correct one. For a face recognition identification only the profile picture of the user is needed. The rest of the attributes are mostly used for informational purposes, in order to create a profile of the client.

Since the id given to users by Facebook is unique and every registered client in the system has a Facebook account, this id is used in every other type of identification when some id is needed to refer a client.

4.2 Wi-Fi sensor

One of the sensors implemented as part of this middleware for identification is the Wi-Fi sensor. This sensor will monitor the network, searching for signals which correspond to potential customers.

The Wi-Fi sensor used in this work is composed by the receiver, a simple Wi-Fi card in monitor mode, and the transmitter, the user's mobile device. Since ubiquity is desired, the choice for these two components was very straightforward. A Wi-Fi card is now a very common component in any computer, and having the users' mobile devices serve as the transmitters removes the need for any other specialized hardware that the user would need to carry otherwise (very intrusive).

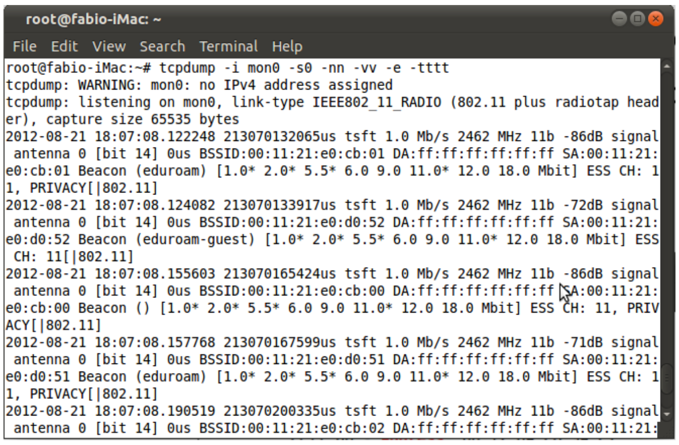
This sensor was developed using *tcpdump*[1] and *iwlist*[2] managed by a Java program, and *aircrack-ng*[3] to set the Wi-Fi cards to monitor mode.

4.2.1 Capturing and filtering network information

In order to capture network information, the following *tcpdump* command is used: "*tcpdump -i mon0 -s0 -nn -vv -e -tttt*". The *-i mon0* simply indicates which interface to monitor; *-s0* is used

[1]tcpdump - www.tcpdump.org
[2]iwlist - http://linux.die.net/man/8/iwlist
[3]aircrack-ng - http://www.aircrack-ng.org

because *tcpdump* does not usually collect the entire packet, and using this option forces it to do so; the *-nn* option disables name and port resolution of the network addresses; *-vv* creates a more verbose output which is easier to read and parse; the *-e* option is very important since it prints the link-level header on each dump line, which, without it, no MAC address would be seen; *-tttt* prints a timestamp in default format proceeded by date on each dump line. An example output of this program call is shown in figure 4.1, showing the packets captured by the network, after the Wi-Fi card has been set to monitor mode.



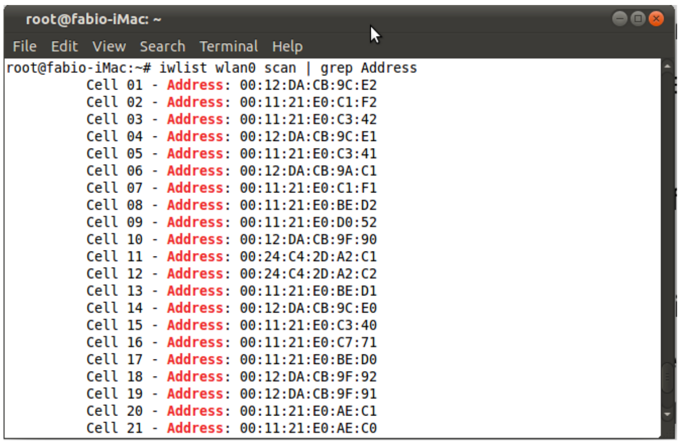
```
root@fabio-iMac:~# tcpdump -i mon0 -s0 -nn -vv -e -tttt
tcpdump: WARNING: mon0: no IPv4 address assigned
tcpdump: listening on mon0, link-type IEEE802_11_RADIO (802.11 plus radiotap head
er), capture size 65535 bytes
2012-08-21 18:07:08.122248 213070132065us tsft 1.0 Mb/s 2462 MHz 11b -86dB signal
 antenna 0 [bit 14] 0us BSSID:00:11:21:e0:cb:01 DA:ff:ff:ff:ff:ff:ff SA:00:11:21:
e0:cb:01 Beacon (eduroam) [1.0* 2.0* 5.5* 6.0 9.0 11.0* 12.0 18.0 Mbit] ESS CH: 1
1, PRIVACY[|802.11]
2012-08-21 18:07:08.124082 213070133917us tsft 1.0 Mb/s 2462 MHz 11b -72dB signal
 antenna 0 [bit 14] 0us BSSID:00:11:21:e0:d0:52 DA:ff:ff:ff:ff:ff:ff SA:00:11:21:
e0:d0:52 Beacon (eduroam-guest) [1.0* 2.0* 5.5* 6.0 9.0 11.0* 12.0 18.0 Mbit] ESS
 CH: 11[|802.11]
2012-08-21 18:07:08.155603 213070165424us tsft 1.0 Mb/s 2462 MHz 11b -86dB signal
 antenna 0 [bit 14] 0us BSSID:00:11:21:e0:cb:00 DA:ff:ff:ff:ff:ff:ff SA:00:11:21:
e0:cb:00 Beacon () [1.0* 2.0* 5.5* 6.0 9.0 11.0* 12.0 18.0 Mbit] ESS CH: 11, PRIV
ACY[|802.11]
2012-08-21 18:07:08.157768 213070167599us tsft 1.0 Mb/s 2462 MHz 11b -71dB signal
 antenna 0 [bit 14] 0us BSSID:00:11:21:e0:d0:51 DA:ff:ff:ff:ff:ff:ff SA:00:11:21:
e0:d0:51 Beacon (eduroam) [1.0* 2.0* 5.5* 6.0 9.0 11.0* 12.0 18.0 Mbit] ESS CH: 1
1, PRIVACY[|802.11]
2012-08-21 18:07:08.190519 213070200335us tsft 1.0 Mb/s 2462 MHz 11b -86dB signal
 antenna 0 [bit 14] 0us BSSID:00:11:21:e0:cb:02 DA:ff:ff:ff:ff:ff:ff SA:00:11:21:
```

Figure 4.1: Sample of packets captured by *tcpdump*.

With these options enabled, the fields needed by the system are present, such as the time the packet was sent, its source and destination addresses, RSS value and type of packet. This output is then parsed to only obtain the relevant sections of the dump lines, creating Wi-Fi events and sending them to the event manager.

It works by capturing all the packets in the network, filtering out the undesirable information. Since the goal of this work is to do identification, the only useful information for this sensor is the information corresponding to potential customers. Since every Wi-Fi device has a unique identifier, the MAC address, it is easy to identify and differentiate incoming packets, grouping them up based on their types. The first step is to filter out the MAC addresses of access points. This is done by doing a network scan with an *iwlist scan* command, sending out probe requests and listening to which devices answer back, as shown in figure 4.2.

This process is made periodically in case new access points enter the area. Since some access points might be hidden, i.e, do not respond to probe requests, any devices that send out beacons are also filtered out. When all the AP packets have been filtered out, it is assumed that the remaining activity in the network is generated by client devices which will be tagged as clients by the system and identified by their MAC address.



```
root@fabio-iMac:~# iwlist wlan0 scan | grep Address
          Cell 01 - Address: 00:12:DA:CB:9C:E2
          Cell 02 - Address: 00:11:21:E0:C1:F2
          Cell 03 - Address: 00:11:21:E0:C3:42
          Cell 04 - Address: 00:12:DA:CB:9C:E1
          Cell 05 - Address: 00:11:21:E0:C3:41
          Cell 06 - Address: 00:12:DA:CB:9A:C1
          Cell 07 - Address: 00:11:21:E0:C1:F1
          Cell 08 - Address: 00:11:21:E0:BE:D2
          Cell 09 - Address: 00:11:21:E0:D0:52
          Cell 10 - Address: 00:12:DA:CB:9F:90
          Cell 11 - Address: 00:24:C4:2D:A2:C1
          Cell 12 - Address: 00:24:C4:2D:A2:C2
          Cell 13 - Address: 00:11:21:E0:BE:D1
          Cell 14 - Address: 00:12:DA:CB:9C:E0
          Cell 15 - Address: 00:11:21:E0:C3:40
          Cell 16 - Address: 00:11:21:E0:C7:71
          Cell 17 - Address: 00:11:21:E0:BE:D0
          Cell 18 - Address: 00:12:DA:CB:9F:92
          Cell 19 - Address: 00:12:DA:CB:9F:91
          Cell 20 - Address: 00:11:21:E0:AE:C1
          Cell 21 - Address: 00:11:21:E0:AE:C0
```

Figure 4.2: Some of the networks seen by the Wi-Fi card.

4.2.2 Locating the individuals

Another very important aspect of this sensor is the ability to gather location information about the mobile devices in the area. This can be done since the signals generated by the devices are emitted with a certain power, which can be measured by the Wi-Fi cards listening. The Wi-Fi cards receiving the packets will be able to measure the RSS of each one and use this information to have some notion of distance. The usual approach to measure distance and determine a location by location based systems would be to triangulate the signals received after a scene analysis of the area, however, these methods assume a constant stream of packets coming from the mobile devices at a very high rate, which is usually achieved by having the client carry some sort of specialized hardware or modified software in their mobile devices, since the use given to the mobile devices by the clients is unpredictable (which would not generate enough information for this type of localization). Given this constraint, the method developed here consists only of two computers acting as listeners (both Wi-Fi cards in monitor mode), which will try to determine a relative position based on as much Wi-Fi activity as they can capture.

From all the signals received, each Wi-Fi sensor will determine if a client is within a certain power range and tag it as a "worthy client" or discard it if the RSS is too low. When a given packet is deemed "worthy", the sensor will generate an event, and send it to the middleware. This event will contain all the information gathered by the sensor, such as the MAC address, time seen and RSS value, as illustrated in table 4.1, and is stored in the event manager.

Wi-Fi event	
MAC address	04:1e:64:ef:bd:37
RSS value	-36dB
Time seen	2012-08-21 12:10:16

Table 4.1: Example Wi-Fi event.

If a "worthy" event is generated by both Wi-Fi sensors in a small time window having the same

MAC address, it means that this network information is being generated from the same mobile device and that it is inside the coverage area, between both sensors. This is seen by the event manager as a meaningful event and will generate a new event type named "wi-fi client event". Only this type of Wi-Fi event will be considered by the developed middleware as a client event for Wi-Fi identification purposes. Using this method, network information generated out of the interest zone but still being picked up by one of the sensors is discarded. Figure 4.3 illustrates this.

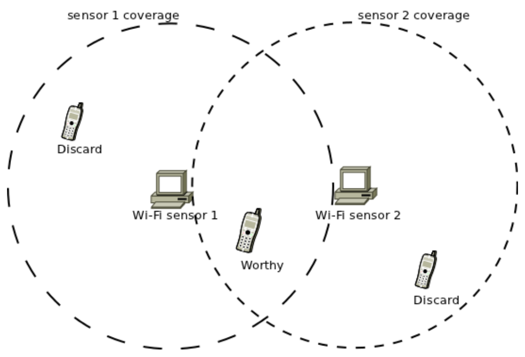


Figure 4.3: Wi-Fi coverage and worthy/discarded mobile devices.

4.2.3 Client association

Having this new "wi-fi client event", more work can be done on the Wi-Fi information collected. As stated before, network information by itself, is pretty much useless for identification purposes, however, when it is associated with a client, the possibilities for this type of information increase. After assigning a MAC address to a client, be it through facial recognition or smart card presence (both methods will be explained in their respective section), any future visits by this client will generate more, and better data for the system, as an identification can now be produced by merely analyzing the Wi-Fi data. Every time a client event is generated, the MAC address information it contains is matched against the system's database, in order to check if it belongs to any registered client. If the MAC address does belong to a registered client, given that it is a unique identifier, an identification can already be made, since it is known that this client is now present in the system's coverage area.

The confidence level assigned to identifications made by the Wi-Fi sensor alone will be of a medium level. Since a MAC address is unique, there is not much room for error when trying to find out if the mobile device originating the detected packet is present in the coverage area or not, making it a very good way to detect the presence of a client.

4.2.3.A Learning mechanism

Given that sometimes more than one Wi-Fi signal may have a strong RSS at the time of association, the system allows for the association of more than one MAC address to each client, which the system stores in the database as pertinent information, ordered by confidence level based on the RSS of the signals. Doing this enables various possibilities for identification. One way of handling this would be to allow the identification of a client to be made from any of the several MAC addresses associated to him, creating a lower confidence value but also a higher identification rate, even if that would mean more false positives. In the current implementation, only the best match is considered. To make the system more flexible, all that is needed to change this identification behavior is modify a simple database query to accept a more wide array of results. Tables 4.2 and 4.3 show an example of Wi-Fi associations made to the client, starting with its initial state.

Client Wi-Fi associations	
Fábio	

Table 4.2: Initial client state.

Mac addresses present	**Client Wi-Fi associations**		
04:1e:64:ef:bd:37	Fábio	04:1e:64:ef:bd:37	-37dB
4c:aa:16:17:47:8e	Fábio	4c:aa:16:17:47:8e	-41dB
00:04:23:bd:b7:08	Fábio	00:04:23:bd:b7:08	-42dB
00:b0:d0:86:bb:f7	Fábio	00-b0-d0-86-bb-f7	-47dB

Table 4.3: First association made to the client (with multiple mobile devices present in the area).

However, since the amount of packets generated by the clients' devices is unpredictable (depends on the activity of the user, if the device is in standby mode or even if it has Wi-Fi turned on or off), an incorrect association of the MAC address to a client might be created, e.g. a mobile device further away from the sensor might be generating higher power signals, confusing the system into assuming that this is the closest mobile device and therefore, it must belong to the user. In order to try and correct this problem, the system learns from every visit made. If a client that had been assigned a given MAC address is detected in a future visit by some other sensor and that MAC address is not present in the coverage area, it is assumed that an error was possibly made in the association step, having measures being taken, from the replacement of the MAC address by a new, more probable one, to a complete reset by the system erasing any Wi-Fi association made to that client. This will allow for future identifications made on a client to strengthen the value of the stored Wi-Fi data, and also for the removal of possible mix-ups from erroneous MAC addresses that happened to be detected in a close vicinity of the client at the same time, which could cause some confusion. Table 4.4 represents the evolution of the Wi-Fi associations made to the example client in table 4.3, by following the process explained here.

Mac addresses present	Client Wi-Fi associations		
4c:aa:16:17:47:8e	Fábio	4c:aa:16:17:47:8e	-41dB
00:08:c7:1b:8c:02	Fábio		
0c:0c:0b:42:ad:e9	Fábio		
e0:f8:47:3b:2f:94	Fábio		

Table 4.4: Posterior association made to the client.

The system thus learns, by making an intersection from the known client associations and the Wi-Fi data present in the area, effectively removing MAC addresses that did not belong to the client and maintaining the most likely ones. This learning mechanism is particularly useful in this case, where the system, in case of ambiguity, associates multiple MAC addresses to each client. While it has the advantages described above, and allows for new ways of identification, more associations to a client also equals a higher uncertainty. As such, by learning from each visit, the system filters out bad associations previously made, increasing the confidence of the identifications.

4.2.3.B Generating the identification event

To avoid an excessive amount of identification events being sent in the system, identifications made by Wi-Fi will only be refreshed every so often, i.e. these events are only produced for each client from time to time. To conserve flexibility and simplicity, to change such behavior all that needs to be done is alter an event statement to accept a higher or lower time interval, more events per interval, among many other options accepted by the event manager. This allows for the administrators configuring this system to set the time intervals which make sense for their applications easily. In the current implementation, the test value of ten minutes was used.

4.3 Biometric sensor

For the biometric sensor, face recognition was the method chosen to perform identification of individuals. This type of sensor was chosen given its innate ubiquitous nature, especially when compared with other types of biometric sensors, and the fact that biometric information is provided when a user registers in the system, the Facebook profile picture. One of the biggest problems of this sensor comes from the fact that a person may have a picture not corresponding to himself or a facial picture containing sun glasses or some sort of mask as a profile picture in Facebook. In these cases, the profile picture is useless as the system will not even be able to detect a face to later use as comparison for recognition. For this reason it is assumed that the clients have a profile picture containing the frontal face of themselves, otherwise, face recognition would not be possible from Facebook information alone.

One of the first problems encountered when using this type of identification was the fact that the normal way of doing it required a large amount of sample images of the users to be recognized. When using the profile picture from Facebook, only one sample image was obtained, which caused some bad results as will be explained in more detail in the current section. To try and resolve this issue, a different approach was experimented for sample image collection. Facebook's graph API also enables developers to access data about a given client's pictures. This data contains information about which people are present in the picture (if they were tagged by their friends) and also the coordinates of the face, which seemed like a very appealing feature. This extra information would allow the system to search for the client's face not only on his profile picture, but in all photos in which the client was tagged. However, this method was not implemented in the final version of this work. Although it seemed like a very interesting way of dealing with the problem, it originated more uncertainty than actually contributing. The problem here is that the tags in the pictures are inserted by humans through a very simple interface provided by Facebook, which pretty much tells a person to draw a square or rectangle around the desired person's face in order to tag it. This means that most of the times these tags would represent an area much larger/smaller than the actual face area, introducing a lot of error. Combining this with the fact that the only coordinates given by Facebook for the face area correspond to the top left corner of that area, and it becomes a lot more difficult to obtain accurate information. After testing with several picture albums of various people, the samples obtained with this method, more often than not, corresponded to incorrect people in the image, effectively degrading the sample data even more. Another interesting case that produces incorrect data is when people take a picture that contains zero faces, but tag it anyway, simply to say that certain people were present when the picture was taken.

The facial recognition part of this work was developed using Microsoft's XBOX360 Kinect as the sensor; OpenKinect[4] to provide the open source drivers, *libfreenect*, that enables the Kinect to be used with Windows, Linux and Mac; Open Source Computer Vision Library (OpenCV)[5] as the library of programming functions for real time computer vision; *haarcascades* to perform face detection in the video frames or pictures of the individual; *libfacerec*[6] as a complement of OpenCV for more specific recognition functions. A Java wrapper, JavaCV[7], was used to integrate this development section in the remaining code, and a Python wrapper was used in order to be able to program both the Kinect interactions and the face recognition algorithm in the same language.

To do face recognition on pictures or video frames from a live video feed, several steps must be followed. The first step is to train the recognition system with a set of facial pictures to be able to later have a matching set for the test pictures. This set of training facial pictures will come from the system's face database, comprised of the profile pictures collected from each individual upon their registration on Facebook, Smart Card pictures in case the client uses the Smart Card sensor,

[4]OpenKinect - http://openkinect.org
[5]OpenCV - http://opencv.org
[6]libfacerec - https://github.com/bytefish/libfacerec
[7]JavaCV - http://code.google.com/p/javacv

and some video frame captures which are stored in very specific conditions. Every face image will be stored in the face database, identified by the clients' respective Facebook id. However, the pictures in this database need some pre-processing before being stored to clean up the facial image for easier recognition. The following steps are used to do this:

4.3.1 Face detection

The pictures coming from the above mentioned sources need to be cropped in order to only save a smaller image which only contains the face section. Figure 4.4 shows a test image in its initial state.

Figure 4.4: Example picture.

This image cropping is done since all image data aside from the face is irrelevant for recognition. For the system to know which area of the image to crop, the face must first be detected. To achieve this, *haarcascades* are used which provide the system with face classifiers, and with OpenCV, using these face classifiers is a lot simpler. Instead of using the facial detection function directly, OpenCV provides a great API to call a face detection function which uses a provided *haarcascade* to automatically detect a face in a given image. Figure 4.5 shows an example of face detection applied to a video frame and the resulting image after cropping.

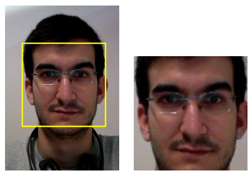


Figure 4.5: Original image with face area marked (left); Cropped facial image (right).

After the cropped image has been created, it is subjected to a series of pre-processing techniques, which are explained in the following subsection.

4.3.2 Image pre-processing

When a cropped image of the face is created, it still needs some processing before it is stored in the database. The reason for this is that most face recognition algorithms are extremely sensitive to lighting conditions, so sensitive that typically when trying to do recognition on a non pre-processed image, the results tend to have under 10% accuracy. Therefore, it is extremely important to apply various image pre-processing techniques to standardize the images supplied to a face recognition system. In the current implementation, the following pre-processing methods were applied:

1. Resize of the images, so that every picture is in the same resolution.

2. Converting the color image to *greyscale*.

3. Apply Histogram Equalization for consistent brightness and contrast of the facial images.

Figure 4.6 shows the cropped image after being *greyscaled* and the final pre-processed face image ready to be stored in the facial database.

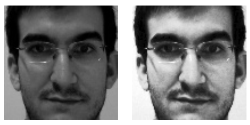


Figure 4.6: *Greyscale* image of the face (left); Equalized *greyscale* facial image (right).

The equalized greyscale face image seen above represents the final state of the image after being subjected to preprocessing, and is now ready to be stored in the face database. These steps are applied to every image given to the system, with the purpose of being used as training data.

4.3.3 Capturing test images

After having the training set ready, test images can be given to the system in order to do face recognition. The previous subsections refer to using a set of methods and software to obtain preprocessed face images from pictures. There is a difference, however, from pictures to live video feed frames. The pictures are simple image files given to the system, either by pulling them from Facebook, using the face picture contained by the Smart Card, or video frames saved in the database in specific occasions. In the work developed, for face recognition to make sense, the test images must come from a real time environment to enable recognition of the people inside the sensor coverage area on the spot. Therefore, the first step is to capture the test images.

To capture images, a camera is required. For the current implementation, Microsoft's XBOX360 Kinect was chosen to perform the captures. A simpler, cheaper camera could also have been used for this function, however, the Kinect is not only a camera, but it is also a sensor, equipped with some features that proved useful in other identification purposes. Since this work was developed in Linux and the Kinect was originally designed to be used with Microsoft's XBOX360, some software configurations are needed before being able to use the Kinect. For Ubuntu (Operating

System (OS) chosen for the implementation), it is required to install the OpenKinect drivers, *libfreenect*, to be able to access the Kinect's sensory functions.

It is now possible to start capturing video with the Kinect. As stated before, the Kinect is not only a camera, but a sensor, having a RGB camera for common video capture and a depth sensor which creates a depth map of what is in range. Figure 4.7 shows a video frame example captured with the Kinect, along with its corresponding depth map.

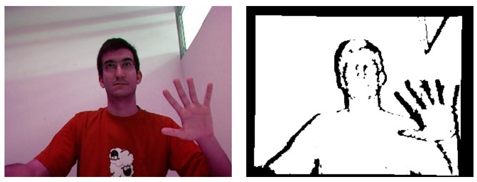


Figure 4.7: Simple video frame captured with the RGB camera (left); Depth map of the environment (right).

4.3.4 Face recognition

Before doing face recognition, the same preprocessing of images as described above, in subsection image pre-processing, is applied to the captured video frames. Since the video being captured is no more than a set of frame images, the exact same process can be applied, once more having only the face section of the image being processed and used for matching in face recognition.

Finally, the system is ready to recognize faces. This is done by taking the face images of the live video feed and matching them to the face database in order to seek which of the stored known faces is most similar. This process is more commonly done using the well-known models, Eigenfaces or Fisherfaces [3]. These models were tested in the development phase and proved to give very bad results. This happens because these models need data to work, the more the better. As such, they are not well suited for conditions such as the ones restricted by this work, which bases itself on using only a small set of training images. Both these methods are based on estimating the variance of the data, requiring a larger training set to do recognition at a decent level. Later, Local Binary Patterns Histograms (LBPH) [1] was used, which proved to work a lot better in this small sample scenario. This method is very different from the other two, since it works as a local feature based method, which is more robust against variations in pose or illumination than holistic methods.

Since one of the most determining factors to decide if recognition is made successfully is illumination, and given that there is no control by the system on the conditions in which the client's Facebook profile picture was taken, another preprocessing method was used, TanTriggs [28], combining it with LBPH, thus creating a more robust face recognition model.

Most of these methods are implemented in the latest version of OpenCV, which was the library chosen to implement this part of the work, using *libfacerec* for some extra functions.

The implementation made in this work is different from common face recognition systems. Instead of taking a face image and attempting only a single match with the face database, several attempts are made from the stream of video frames being fed to the system. This method allows to make a somewhat inaccurate system more reliable, only accepting a recognition as successful if a training face is chosen as the best match 70% more times than other potential faces, from at least 20 recognition attempts (20 different video frames). An example of this evaluation process is illustrated in table 4.5.

Match	Occurrences	Best match
Fábio	15	X
Hugo	3	
Eduardo	2	

Table 4.5: Successful recognition from video frames.

If, however, no match reaches the 70% acceptance rate, or not enough samples have been provided, the recognition is considered as failed, as demonstrated in table 4.6.

Match	Occurrences	Best match
Fábio	10	
Hugo	6	
Eduardo	3	
Scarlett	1	

Table 4.6: Failed recognition from video frames.

This acceptance threshold of 70% was chosen after some testing, which proved to give good balance over client recognition and false positives. The value can be easily configured, to serve different requirements, enabling a more robust and precise recognition with lower recognition rates, or higher recognition rates with a higher number of false positives.

If a person leaves detection range/pose the current capture is terminated, generating a result if the match attempts reached its minimum required value, or simply resetting the algorithm, making it ready for the next face.

4.3.5 Face distance

Besides the previously mentioned processes, another important feature for this work is the detection of how far away the client is from the camera. This is done using the Kinect's Depth sensor and it's open source library, *libfreenect*. As was demonstrated in figure 4.7, the depth sensor creates a depth map of the area, allowing developers to access information about this map. Using *libfreenect*, it is possible to describe this map as a matrix, where each position corresponds to a given point in the image, containing the distance value of each point in millimeters.

Figure 4.8 demonstrates face recognition working over video frame images, with this distance method applied.

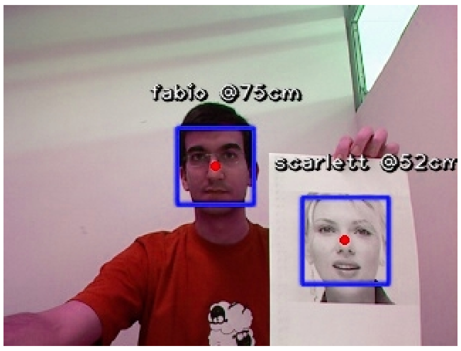


Figure 4.8: Face recognition with distance measurements.

This distance measurement of the face is done by capturing the area of the face, accessing its central point, and using the distance value of this point (typically it corresponds to the nose), as illustrated in figure 4.8 as the dot in the center of the face.

Distance is important because it allows the system to isolate faces in the camera's range. When several people are in range of the Kinect, the face detection algorithm detects every face in the area. This can have its uses for other applications or future work, however, for face recognition, it would only generate confusion when trying to match the several test images at the same time. As such, only the closest face is considered by the system, since it is more likely that the closest person is the one doing some sort of relevant action near the camera (e.g. using the smart card). With this face isolation, confusion in the recognition of a person is greatly minimized.

4.3.6 Generating the events

When a recognition is made, it must be evaluated to decide if it has been successful or not. In case of success, the sensor will generate an event named "camera client" and send it to the event manager. This event will have information regarding the recognized client, in this case, its Facebook id, which is the unique identifier associated to each client. This event always corresponds to a registered client since failed attempts of recognition do not generate any event in the system. From this event, the middleware knows that this client is present in the coverage area, the time of the occurrence, and the position of the user inferred from the depth information of the Kinect.

At the time of this identification, more complex events can be generated if enough information is available. By having an identification being made from the client's face, a direct connection can be made to that client's profile, opening up more possibilities, namely for the Wi-Fi sensor. Every time a face is detected by the system, a storage of Wi-Fi events begins. These events are continuously stored as long as that face is being detected. When the face leaves detection range/pose, the Wi-Fi event storage is stopped and an analysis of the stored events is performed. From all the events gathered, the RSS values corresponding to each of the collected MAC addresses are taken into account, creating a table of MAC addresses and their respective RSS median values as illustrated in table 4.7.

MAC address	RSS values (dB)	Median RSS value (dB)
04:1e:64:ef:bd:37	-37	-37
04:1e:64:ef:bd:37	-35	
04:1e:64:ef:bd:37	-38	
04:1e:64:ef:bd:37	-36	
04:1e:64:ef:bd:37	-37	
04:1e:64:ef:bd:37	-37	
4c:aa:16:17:47:8e	-42	-44
4c:aa:16:17:47:8e	-44	
4c:aa:16:17:47:8e	-50	
4c:aa:16:17:47:8e	-44	
00:04:23:bd:b7:08	-44	-45
00:04:23:bd:b7:08	-43	
00:04:23:bd:b7:08	-47	
00:04:23:bd:b7:08	-48	
00:04:23:bd:b7:08	-45	

Table 4.7: Meaningful Wi-Fi events during face detection.

The median of the RSS values was used since it is a good method of estimating the most likely Wi-Fi signal from their RSS values, while also discarding outliers which sometimes occur and would negatively affect the final estimated value. From this new table of values the most likely MAC address can be inferred, knowing that the client is the closest one to the camera, the most likely mobile device to belong to him would be the device generating the Wi-Fi signals with the strongest median RSS. This MAC address is then associated to the client, by inserting it in the database, in that client's profile. After the association has been made, the stored Wi-Fi events are cleared.

Another type of complex event can also be generated if a face recognition identification is made while a client is using his identifying smart card. In this situation, a strong correlation is made, since it is known with a much higher confidence, that the face in front of the camera is indeed who the system claims it is, given that the identification is being backed up by the smart card information. Given this stronger identification, from the combination of these two sensor identifications, the system is able to make some additions to the client's data. This is done in the form of a new face image being stored in the facial database, corresponding to that client. The reason why this is useful is because of the low confidence of the original pictures in the database. The profile picture pulled from Facebook was taken in unforeseen circumstances and in an unknown scenario, introducing a lot of error, such as face expression and illumination. By storing a new face picture of the client, taken by the Kinect inside the coverage area, this new training image will have been taken in the exact same conditions as the test images for recognition, generating much higher confidence identifications from that moment on.

In any case, when a "camera client" event is generated by the sensor, all information from the client is gathered and a more complex "registered client" event is generated and sent to the registered applications. The confidence value of these final events is restricted by the identification conditions. If an identification is carried out solely from information collected by the biometric sensor, it's confidence will be low, because of all the unforeseen circumstances and possible errors described throughout this section. If, however, an identification is made by the biometric sensor while the MAC address of the identified client is also present in the room, the confidence will increase significantly. Best case scenario is the identification of an individual being made by face recognition, from a client which already has the extra face picture stored in the database, while his Wi-Fi id is also present, generating the highest confidence possible from face recognition identifications. Table 4.8 is shown to better illustrate these various confidence levels.

Identification	**Confidence level**
Face recognition only	Low
Face recognition backed up by smart card data	Low-Medium
Face recognition + Wi-Fi detection	Medium-High
Face recognition + Wi-Fi detection backed up by smart card data	High

Table 4.8: Confidence levels associated with face recognition identification.

4.4 Smart card sensor

The smart card sensor was also implemented in this work, providing a strong identification element, when an unequivocal identification of an individual is required. This is the most intrusive part of the developed system, since it requires the user to have an interaction with the system by inserting his identifying smart card into a reader. Given that some applications might need this strong identification, it justifies its use.

This type of sensor was chosen taking into consideration that most countries already make their citizens carry a citizen card, which is a secure smart card containing authentication applications which identify an individual in a safe and reliable way, and are not easily forged or copied. The fact that these cards are nowadays part of everyday life and people always have them on their person, and having the smart card be a relatively small and light product, minimizes the intrusiveness of the sensor. Figure 4.9 illustrates the sensor setup.

This sensor is placed on the same machine that is equipped with the Kinect. It consists of simply connecting a smart card reader to the computer and installing some specialized software. The smart card reader used in this implementation was the *gemalto* PC USB-TR[8] which is flexible for deployment and easy to use. The software required to install the reader can be found in the company's website in the support section and drivers download. The installation software is dependent on the reader used. The smart card used also requires some specific software to en-

[8]Gemalto - http://www.gemalto.com

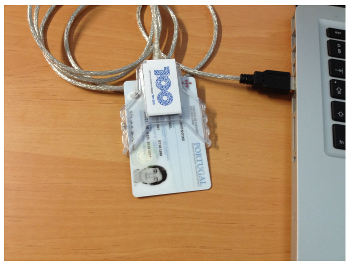
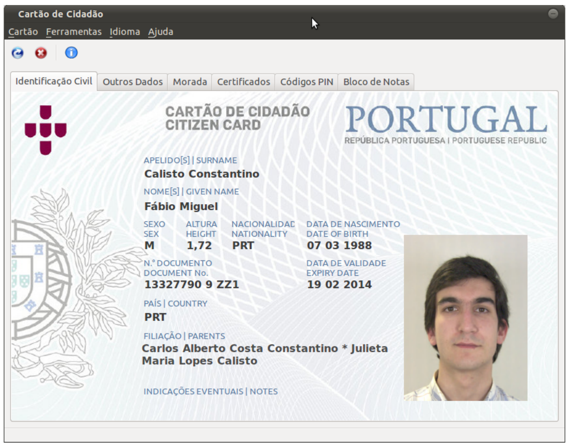


Figure 4.9: Sensor setup.

able communication between the reader and the card, and accessing the card's data. The smart card used for testing was the Portuguese Citizen Card, a smart card which contains important information about their owner and is required by law that everyone carries it. Its software can be found on the Portuguese Citizen Card website, containing information about its usage as well as technical manuals. Upon installation of the citizen card's software, one specific library is installed which is important to refer. The *(Portugal eID Library) (pteidlib)*[9] is contained in every installation and was used to make direct accesses to the smart card's data. This sensor was implemented in Java, using the *pteidlib* as the API to retrieve information from the card. Figure 4.10 shows the output of the citizen card application.



APELIDO[S] | SURNAME
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NOME[S] | GIVEN NAME
Fábio Miguel

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Carlos Alberto Costa Constantino * Julieta Maria Lopes Calisto

INDICAÇÕES EVENTUAIS | NOTES

Figure 4.10: Portuguese Citizen Card application output.

The sensor is configured to get the reader ready as soon as the system is turned on, putting it on a standby mode where it waits for a card to be inserted. Upon the insertion of the card, communication with it is initialized and all relevant information about the client is retrieved. This is easily done with the functions provided by *pteidlib* which serves to abstract the low level, much harder to understand Protocol Data Unit (PDU) communications. Information such as illustrated in figure 4.10 is obtained and the facial picture of the client is also stored in the system's facial database. This action will also trigger the generation of a "smart card event" which is sent to the event manager, trying to figure out if the card belongs to a registered user. This event contains

[9]pteidlib - http://www.cartaodecidadao.pt

all the information retrieved from the smart card: name; gender; date of birth; nationality; civil id number; parents names; facial picture. When the event is received by the event manager, the system will look in the known users database searching for users with similar names. The search is not made trying to find an exact name match since the names used in Facebook might be a bit different from the user's real name, caused by things such as the absence of accentuation or the omission of middle names, as explained previously in the privacy & registration section. As such, more than one user might seem like a positive result, given that people with the same name are a reality. To further specify the search and remove the bad candidates, the birth date of the individual is also matched. If more than one user is found by searching a name, the birth date will certainly thin out the result space. If there is still some ambiguity in the identification (users with the same name and same date of birth) the face recognition algorithm is called, using the photo contained in the smart card as the test image.

After a user is successfully identified with the smart card, the client profile is updated, replacing the Facebook name with the one in the citizen card which is the complete and exact name of the person, the date of birth which might not have been filled in on Facebook is also replaced by the one in the citizen card, and all remaining information retrieved from the card is added to the client's profile. Another important addition is the facial picture present in the card, which is also added to the facial database of the system, increasing future facial recognitions. This sensor is, thus, not only adding to the knowledge of the system but also actively improving the information present in the system's database with more accurate data. Given the nature of the sensor and the card used, identifications produced by it will have the highest confidence in the system.

The high confidence of this sensor enables for good associations to be made with the other sensors. An important factor that is taken into account for this is the timing and location. Since this sensor requires the insertion of the smart card in the reader, the location of that client is known with good accuracy. Having the sensor placed in the same machine as the one equipped with the Kinect enables face recognition to be performed while the client is using his smart card, and knowing the location of the client also allows for accurate association with Wi-Fi information.

4.4.1 Combining the events from other sensors

When a person uses the smart card, an event is triggered, warning the system of the presence of a card. At this time, the event manager will start combining events generated from the smart card sensor with the ones from the Wi-Fi sensor. The information contained by both events will be joined in a more complex, combined event. These special events are only generated while the presence of a smart card is detected. Since the events generated from the Wi-Fi sensor contain information about the RSS of the signals present in the area, it is possible to determine which is the most likely mobile device of the client. An interesting characteristic of these combined events is the fact that there is no repetition of identifiers. What this means is that instead of creating a new data structure to store the Wi-Fi information and later look at it, the event manager is capable of processing the events in such a way that when a new Wi-Fi event is received, all the events with the same MAC address identifier are grouped up as one while having the median of the RSS calculated simultaneously.

Just as is done with face recognition - Wi-Fi associations, a learning mechanism is also implemented here. Since there might be more than one likely mobile device in the area, associations of more than one mac address are also possible here. Just as before, the system learns from repeated visits by the client, updating its profile, strengthening the correct data and filtering out the bad.

Face recognition information being added to the system is the big difference here, as it was not possible with any other sensor. Since the smart card sensor provides such strong confidence in its identifications, and knowing that the user is in front of the Kinect at the time of that identification, face images of the individual can be gathered and added to the facial database, strongly contributing to future face recognition identifications being made.

4.5 Event manager

In the architecture tools section of this dissertation, the event manager software used in this work was explained. However, it has been mentioned throughout the chapter, that events are generated by the sensors and sent to the event manager, without fully detailing it's functionality. The present section intends to shed some light on the components developed to make this work.

The event manager is essentially a software component which is prepared to receive events from multiple sources, passing each one through defined rules which will analyze these events and decide if action needs to be taken upon them. Events are simple Java objects, which are a simple, rich and versatile way to represent them in Esper. Maps and Extensible Markup Language (XML) were alternative methods of representing the events, but given the development environment for this work, Java objects was the most adequate choice.

Esper also provides a programming language, EPL, which allows developers to create statements, similar to the well known SQL queries, to analyze and filter the events coming in. These are continuous queries registered with an Esper engine instance that provides results to listeners as new data arrives, in real-time, or by demand via the iterator (pull) API. Listeners are invoked by the engine in response to one or more events that change a statement's result set.

4.5.1 Event Stream Analysis

The above mentioned EPL statements derive and aggregate information from one or more streams of events, to join or merge event streams, and to feed results from one event stream to subsequent statements.

As was referred, the EPL language is similar to SQL, especially in its use of the select and where clauses. However, these statements instead of using tables use event streams and a concept called views. These views will define the data available for querying and filtering, and can represent windows over a stream of events. They can also sort events, derive statistics from event properties, group events or handle unique event property values.

This is a sample EPL statement that looks at client events and filters the registered client ones:

```
select * from Client where fb_id is not 0
```

Since the sensors (especially Wi-Fi sensors) can generate a lot of events corresponding to registered clients at a very fast pace, this statement can be altered to only accept the first registered client event that arrives for each identifier:

```
select * from Client.std:firstunique(fb_id) where fb_id is not 0
```

With this new statement, the event manager will keep track of every registered client event being received and only accept the first one. This will, of course, accept the first client event for every distinct identifier, otherwise only the first registered client entering the coverage area would be identified, and that would simply not do! What this alteration does is make the event manager "remember" the client identifiers received, accepting the first registered client event with a new identifier and discarding all the others which had already been seen.

One problem that is easy to spot with this statement, is the fact that for the entire time the system is running, a client would only be identified once. This might be useful for some applications, but it is not the case here. As such, another alteration to the statement is required, which will change the behavior of the event manager to only "remember" a client identifier for a limited amount of time, i.e. after this time has passed, a previously seen registered client can once more be identified:

```
select * from Client.std:firstunique(fb_id).win:time(10 min) where fb_id is not 0
```

This statement is now set to only accept the same client identification event every 10 minutes through the use of a configurable time window.

As was just shown, statements can easily be altered to answer specific needs, such as demonstrated by these constraints. Many other different statements were used in the development of this work, some as simple as the one shown here, others much more complex. Each of them are used to answer specific needs and every single one can easily be modified if needed.

Five types of operators are available to use in statements:

1. Operators that control pattern finder creation and termination: every
2. Logical operators: and, or, not

3. Temporal operators that operate on event order: -> (followed-by)

4. Guards are where-conditions that filter out events and cause termination of the pattern finder, such as timer:within

5. Observers observe time events as well as other events, such as timer:interval, timer:at

Finally, by attaching a listener to the statement the engine provides the statement's results to the listener which can then do further work on the received data. These are used to do operations over the data contained in the events, such as e.g. interactions with the system's database to match some of the event information received with it.

4.5.2 Event synergy example

Now, for a better explanation of the synergy between the sensors, another example is shown here, detailing a more complex query involving the data generated from two distinct sensors:

```
"insert into CombinedEvent(macAddress, lastSeen, dbValue, name, gender, " +
   nationality, birthdate, civilIdNumber, timeSeen)" +
                         "select WorthyWifiClient.macAddress," +
                              "WorthyWifiClient.lastSeen," +
                              "WorthyWifiClient.dbValue," +
                              "SCClient.name," +
                              "SCClient.gender," +
                              "SCClient.nationality," +
                              "SCClient.birthdate," +
                              "SCClient.civilIdNumber," +
                              "SCClient.timeSeen ";
```

where the *CombinedEvent* is a new event structure, created to hold the data shown here, *WorthyWifiClient* is the event being sent from the Wi-Fi sensors after all have decided that the MAC address does indeed correspond to a client (as explained in section 4.2) and the *SCClient* corresponds to the event type being generated by the Smart Card sensor upon the insertion of an identifying smart card by a client (note that *dbValue* is the RSS measurement). This statement is essentially saying that whenever a smart card is being used, all of the events generated by the Smart Card sensor and the Wi-Fi sensor are combined into the new event type, *CombinedEvent*. As is simple to understand, if there are no Wi-Fi events being generated at the time, no combined events will be created, and the same applies to the time periods where there are no smart cards being used.

This new event not only holds the information of the two simpler events, but also another very important piece of data. Knowing that this combination of events was generated at the same time, and by knowing where the Smart Card reader is, the system is now aware of location and timing relating to the individual. Adding to this the data collected by the Wi-Fi sensor about the RSS of the signals, and it is possible to check which of the detected mobile devices in the area is closer to the Smart Card reader. After realizing this, the next logical step is to make the association between the Smart Card data and the most likely network id, correlating the information and adding to the personal profile of the client. From this point onward, if the MAC address was previously unknown, it will now be enough to identify the individual in future visits. In case the MAC address was already associated with the individual by some other mean, e.g, biometric association, the smart card data will strengthen the confidence of any future identifications made with this MAC address.

This can be done by creating another statement:

```
"create context averageRSSContext30Sec initiated by "+
 "pattern[every-distinct(a.macAddress, 30 sec) " +
 "a=CombinedEvent]@inclusive terminated after 30 sec");
```

In this statement, the event manager will now look at every generated *CombinedEvent*, for 30 seconds after the detection of the first one, i.e, immediately after the insertion of a smart card, and for 30 seconds it will collect all the *CombinedEvents* generated for each MAC address. After this time, the pattern will reset. This time constraint serves only to limit the number of events analyzed, focusing on the most relevant, the ones generated at the time of the smart card usage. Another option would be to use different time windows or simply look at every single event generated for the full duration which the card remained in the reader, possibly introducing more room for error by adding more network communications by different mobile devices into the analysis. In order to provide a faster result and try to minimize error, the exemplified approach was the one used.

With this, another statement can then be created, making use of this intermediate filter:

```
"context averageRSSContext30Sec select civilIdNumber, name, gender, birthdate, " +
       "macAddress, median(dbValue) as avgDbValue, count(*) as count from " +
       "CombinedEvent(macAddress=context.a.macAddress) output last when terminated")
```

This new statement will be the last one for this analysis, creating a context which uses the previously shown statement and gathers all the relevant information contained by it. It will also add two new pieces of information to the result, the count and median RSS of the received events, grouping them up by MAC address, making it easier to understand and adding value to the identification. This statement will provide the event manager with the needed information to make a good and robust association between the smart card data and the Wi-Fi data, by looking at the RSS median and the number of network packets collected. The mobile device generating the highest value median and with a sufficient number of packets generated, will thus be associated as the best match for the client identified by the Smart Card.

The information collected by this set of statements will be seen by a listener added to this final statement, which will be responsible for ordering the events, based on how good a match they are, and inserting all of the information into the system's database.

4.6 Final output

Throughout this chapter, the implementation details and choices made in the development of this work have been presented. However, after an identification has been made, something must be sent to the applications registered in the middleware. Since these applications are only concerned with the identification results, there is no need for them to also implement an event manager in order to manage the final events generated by the system. As such, when the system detects that a good identification event has been generated, all the information contained by this event is converted into XML format using the *xstream*[10] library, making it ready to deliver to the applications. XML format was chosen since it provides simplicity, generality and usability. This *xstream* library also simplifies things, since it is capable of serializing Java objects into XML and back again through a very simple API, making the conversion of any type of event a breeze. The fact that XML is a universally accepted language, using this type of output will make it simple for any application wanting to use the middleware, to read and parse the output though one of the many available APIs for XML parsing.

[10]XStream - http://xstream.codehaus.org

5 Tests and results evaluation

Contents

In this chapter some of the experimental results are shown regarding the identifications obtained from several individuals by the system.

5.1 Test contextualization

The main focus of this work has always been the identification of individuals. This identification is to be done through several sensors, each of them collecting a specific kind of information, but what is most important is the information gain by correlating the data being generated by the various sensors, along with extra information such as time, location, and repeated visits of the customer.

In this chapter, various test scenarios are presented, and the information collected, along with its confidence level is shown for each identifying sensor, as well as for the overall system.

The test environment consists of a small room with 2 computers, each equipped with a Wi-Fi sensor and placed on opposite sides of the room, having the Kinect and smart card sensor placed on the furthest machine from the entrance. The social network sensor and system database are placed in another computer, not present in the room. Throughout this chapter, the machines will be referenced as machine 1 (computer at the end of the room, equipped with Wi-Fi, smart card, and biometric sensor), machine 2 (computer near the entrance of the room, equipped with a Wi-Fi sensor), and machine 3 (computer not present in the room, equipped with the system's database, and social network sensor). Every scenario presented contains at least one individual inside the coverage area, and every individual is equipped with a personal Wi-Fi capable device and identifying smart card (Portuguese citizen card). The machines are connected via ethernet. For testing, 7 clients were registered in the system.

The following test cases were created:

1. Non-registered individual enters coverage area, walks to the end of the room, does a simple action in front of machine 1 and then leaves.
2. Registered user enters the coverage area of the system for the first time and stays in the room for a while. During this time he walks around the room, stops to perform an action with his smart card and then leaves.
3. Same user from test 2 re-enters the coverage area, walks around the room and leaves.
4. Two registered users enter the room. User B stays idle near the entrance while user A walks to machine 1 and does an action requiring the use of his smart card. Both users leave at the same time, after user A's action is completed.
5. User A from previous test enters the room with a different registered individual. They both walk around the entire room making quick stops at each machine and then proceed to leaving the area.

6. Registered user carrying 2 mobile devices was identified by the system in an older visit. This same user now enters the room with only one of those mobile devices.

These test cases were chosen since they demonstrate how the system deals with most of the possible situations, and how the confidence levels in identification grows as the system learns more from the individuals.

For the evaluation of these test cases, a graph is produced to better illustrate the information gain of the system. It will show the confidence levels of the identifications done by the system over time, qualitatively evaluating these values over 3 different levels: low, medium, and high. It is important to note that the graph will depict the confidence level at each time, taking into account the amount of sensors identifying the individual at that given time and the amount of data that the system has for that person. Every time an identification is made, it is also displayed in the graph a simple annotation indicating which sensor(s) generated it, represented by the initials of their respecting sensors: w for Wi-Fi identification; b for biometric identification; sc for smart card identification.

5.2 Scenario 1 - Unknown individual

For this test, an individual not registered in the system was sent into the coverage area of the sensors. The test results obtained were expected, as no identification was made.

The individual's Wi-Fi signals were detected by both machine 1 and machine 2 while he was inside the room, however, since no association had been made to the collected MAC address, the system assumed it was from an unknown person. When the individual spent some time in front of machine 1, his face was captured by the Kinect camera and face recognition was attempted. As explained in the implementation section of the biometric sensor, the face recognition algorithm created tries to identify a person multiple times, and only considers that a correct identification was made if one of the match possibilities is matched 70% more times than the others. When the system tried to do face recognition of this person, it did not reach the accepted threshold, and therefore, was unable to do identification. Since the system had no knowledge from this user's social network information, there was no sample picture of this person in the facial database, leading to much less accurate matches from the recognition algorithm.

5.3 Scenario 2 - Registered individual, first visit

In this scenario, a registered client is brought into the room to interact with the smart card reader. This test was successful as identification events were generated from multiple sensors during the presence of the client. The best identification made was of the highest level possible, generated by the smart card sensor.

Figure 5.1 shows the graph of the confidence levels of identification throughout the experiment, based on the information gain of the system.

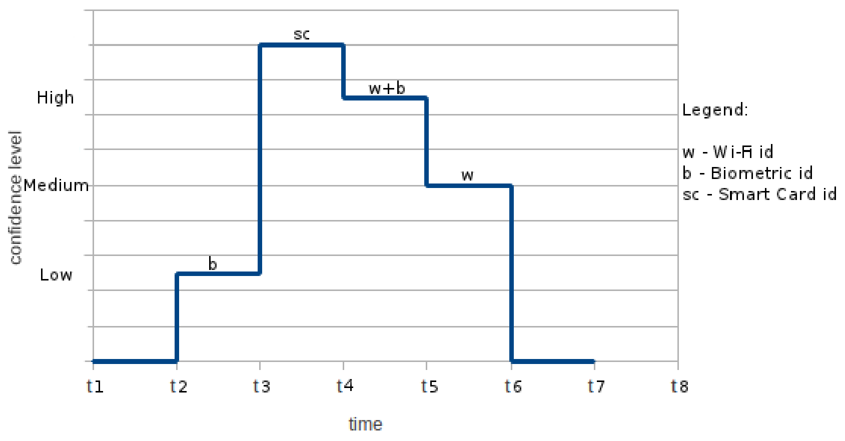

Figure 5.1: Confidence level of identifications for scenario 2.

Some time after the entrance of the client in the coverage area, represented by instant t1, Wi-Fi communications from his mobile device were detected by the Wi-Fi sensors. However, no identification events are generated since this is the client's first visit, and Wi-Fi data has not yet been associated with his profile.

As can be seen on figure 5.1, the first identification provided by the system, at instant t2, is of low confidence. This moment corresponds to the time when the client entered the Kinect's camera range. As soon as the client's face was captured by the Kinect, the facial recognition algorithm was initialized and, after 7 seconds, the client was identified by the biometric sensor. Since at the time the only information in the system was the data pulled from Facebook upon this client's registration, identifications produced through face recognition have a low confidence. However, an association was also made between the client in front of the camera and the Wi-Fi signals present in the room, effectively increasing the knowledge of the system, complementing the client's profile with Wi-Fi information.

The next relevant part of the graph corresponds to instant t3 where the client inserts his identifying smart card into the reader. This time the system will gain a lot of information about the client, as this is the highest confidence sensor in the system, producing the best identification event possible. Not only this, but it will also improve and add data to the client's profile, effectively augmenting the system's knowledge about this person. Once more, Wi-Fi data was checked, improving the current association, and a new facial picture of the client was added to the facial database.

After the client has finished his action, the smart card was removed and the level of confidence for identifications from this moment on decreases, since an identification from the smart card sensor is no longer possible. In this particular test, when the client removed his card, he looked down to do so, resetting the face recognition algorithm. As such, after the card was removed, another facial recognition was made, identifying the client once more, but this time with increased confidence. The reason behind the better confidence level of identifications generated from the biometric sensor is because of the added information from the smart card associations. Not only is there an extra facial picture in the training set providing more reliable recognitions, but since there is now an association between the client's face and Wi-Fi data, and the client's Wi-Fi id is also being detected at the time of the identification, the confidence level will rise even more. This is evidenced at instant t4.

When the client leaves the detection range of the Kinect, all that is left to identify him now are the Wi-Fi sensors. Contrary to the first time the Wi-Fi data from this client is detected, the system can now generate events since it now has knowledge about the owner of the mobile device generating this data. As can be seen in the graph at instant t5, the confidence level of the identification generated by these sensors is of medium confidence.

When the client leaves the coverage area, at instant t6, the confidence level falls to 0 which indicates that no identification of this individual is possible, given that no sensor is able to capture any identifying feature of the person.

Even though this test was successful, there are certain problems that might have occurred to make it generate some incorrect identifications. In the event that the face recognition generated an identification event corresponding to an incorrect client, the Wi-Fi association of this mobile device would be made to that incorrect client. This would generate some bad identifications until the system realized there was a problem using the learning algorithm. The same problem might occur if the client does not have a mobile device or is carrying a mobile device that does not belong to him. These problems are also corrected with the learning mechanism, however, it is assumed that the users only carry their own personal devices.

5.4 Scenario 3 - Registered individual, repeated visit

This scenario is very similar to the previous one, once more including just one person (same client from the previous test), but this time the individual is not visiting for the first time, i.e. the system already has good associations made to this person and possesses a lot of relevant data in his profile. The results were good, as a correct identification of the individual was obtained. The best identification level achieved was "High" since this time there was no use of the smart card.

Figure 5.2 shows the results graph of this experiment.

As is shown in the result graph, instant t1 corresponds to the entrance of the user. At the time, no identification has been made because no Wi-Fi signals have been detected by the Wi-Fi sensors. After a few seconds, while the client was walking around the room, the first Wi-Fi

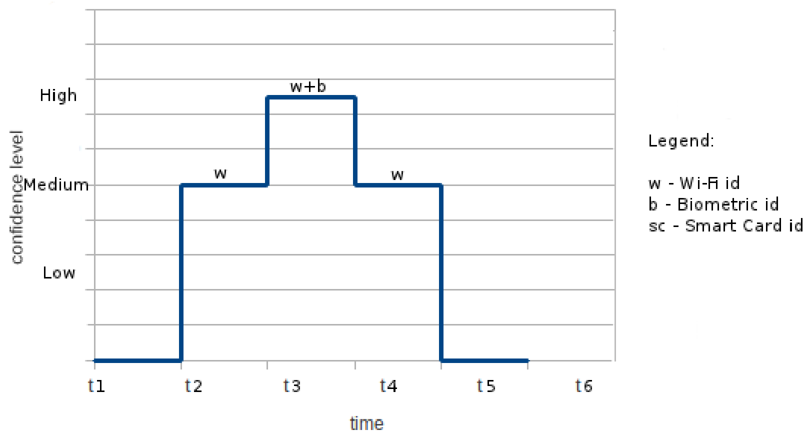

Figure 5.2: Confidence level of identifications for scenario 3.

signals were detected by the sensors and, this time, since a previous association of this type of information had been made, an identification was possible. Instant t2 represents the moment where the identification is made, generating an event containing all current information about the client.

Throughout this experiment, the client also spent some time in the area in front of the Kinect. During this time, several face recognition attempts were made, where 2 out of 5 attempts were successful. This happened because the user, while having his face detected, by moving around changed his pose into an undetectable angle, causing the recognition to be interrupted before the minimum required number of frames had been captured. In both times that an identification event was generated, the user was correctly identified by the biometric sensor at instant t3. These identifications however, were not made in perfection. During one of the biometric sensor identifications, no Wi-Fi signal from the client was detected. This can happen since the default Wi-Fi activity of mobile devices is unpredictable if the user simply has Wi-Fi turned on, but is not actually using it. As such, one of the identification events was generated with a "High" confidence level, where the other one merely had a "Low-Medium" confidence. In the graph, only the highest one achieved is represented.

Instant t4 is when the user leaves the Kinect's coverage, and only Wi-Fi identifications can be made. The level of confidence of these identifications is the same as at the start since no information was altered in the user's profile, dropping to 0 when the client leaves the room and can no longer be identified by any sensor at instant t5.

5.5 Scenario 4 - Multiple registered individuals, first visits

This fourth scenario introduces the concept of multiple individuals in the test area at the same time. This particular test required the participation of two individuals, both registered in the system, where one of them (user A) walks around in the room and interacts with the smart card reader while the other person (user B) stands idle near machine 2. Both users were visiting the system's coverage area for the first time. The results produced by this test were expected, generating the highest confidence identification possible for user A and no identification being made for user B as shown in figure 5.3, having a line representation for each user.

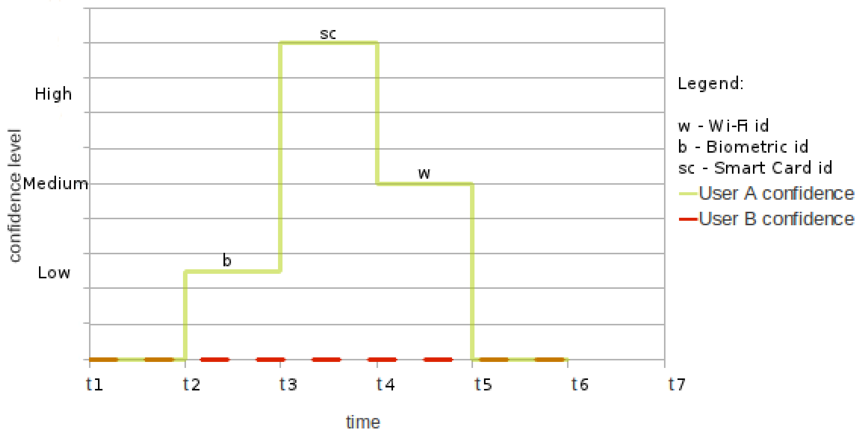

Figure 5.3: Confidence level of identifications for scenario 4.

While having no identification being made for user B sounds like a negative result, it is quite normal. Since it is the first visit from this user, even when his Wi-Fi signals are detected, the system is not aware of any previous connection and will, therefore, tag it as a random mobile device. Given that for this test the user is left idle near the machine 2, no other sensor will sense this person's presence making information association and subsequent identification not possible.

User A however, is recognized by all the sensors. Initially, at instant t1, when the user enters the room, no identification is provided, for the same reason as user B. Even if Wi-Fi communications are detected from the user, given that it is the first visit he makes, the system has no knowledge that the Wi-Fi data actually belongs to him.

At instant t2, the client sits in front of machine 1 and even before inserting his smart card, is identified by the biometric sensor. This identification is successful, even if barely reaching the minimum threshold required. Before the user inserted his card, he spent some time sitting in the coverage area of the biometric sensor, chatting with user B. Given the movements of user A's face, the recognition algorithm was reset several times, doing 7 more recognition attempts. Out of these 7 attempts, 4 failed to reach the minimum required frames and out of the remaining 3 attempts, 2 were successful and 1 generated an identification event indicating the presence of a different user. This type of error is more evident in users for which the Facebook profile picture is not very adequate. Just as was explained in the face recognition section, factors such as illumination, head position and contrast heavily affect the recognition results. The correct identification's confidence level for this recognition is shown in the result graph at instant t2.

Upon the insertion of the client's smart card at instant t3, an identification event is generated producing the highest confidence level of any identification, just as in test scenario 2. The difference here is when the system tries to make an association of the Wi-Fi events being generated in the area with this client's profile. This time there is more than one person generating Wi-Fi events, and events from user A and user B are both seen as valid data, for which the system inserts them in user A's profile, which could generate some confusion in specific occasions.

Instant t4 represents the removal of the smart card by the user. At this time, the user immediately stands ups and walks away from machine 1, not giving any time for the biometric sensor to do any kind of recognition. Therefore, the next identification event being generated came from the Wi-Fi sensor, which now sees the network data as something relevant. As was mentioned in the previous instant, an incorrect Wi-Fi association was made to user A's profile, which would cause some problems. However, given the current implementation choice of the system to only consider the most likely network address for identification purposes, the fact that at the time of the association the Wi-Fi signals being generated from user A's mobile device had a stronger RSS than user B's, and knowing that this type of information is ordered by relevance before being stored in a client's profile, the identification given by this sensor was still accurate. In a future visit, when user A makes use of his identifying smart card again, the learning algorithm will be employed, removing the second Wi-Fi association and strengthening the confidence of the association that remains.

Instant t5 represents the exit of both clients from the room.

5.6 Scenario 5 - Multiple registered individuals, repeated visits

This test scenario brings no new information about the identifications being made or the confidence levels achieved, it serves only to better illustrate the difference in confidence from identifications made on clients with rich profiles and those with basic ones. Once more, two registered users enter the coverage area of the system. One of these clients, was also present in the previous test, user A. The other client (user C) is also entering the room for the second time, however, on his first visit, he did not use his identifying smart card, leading to less information gain by the system. To better demonstrate the difference in levels of identification between these two clients, the two individuals did the exact same route through the room, being subjected to the same tests.

Figure 5.4 represents the various identifications done for the two clients, each one represented by a different line in the graph.

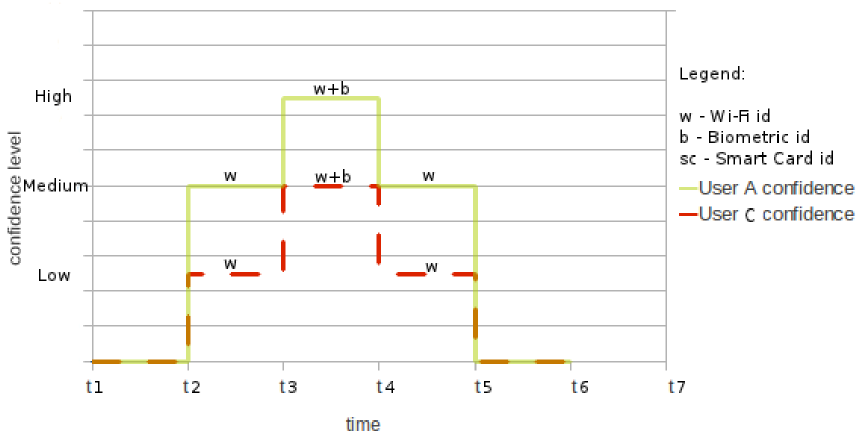

Figure 5.4: Confidence level of identifications for scenario 5.

As can be easily compared, user C's identification confidence levels are much lower than the ones made for user A, roughly 50%. This shows the relevance of the smart card sensor, even though it is the most intrusive sensor in the system, it represents a very strong identification and correlation point. Instants t2 and t3 represent the identifications made to each individual by the Wi-Fi sensor alone, and face recognition along with Wi-Fi data respectively. Instant t4 is when the users leave the Kinect's area of coverage and t5 when the users leave the room.

This test also reinforces the idea that even if the system does not have information from all sensors, an identification is still possible, even if it is made with a lower confidence level. These lower confidence identifications are still very important to the system, as some registered applications might not require a strong identification in order to do their work. If only high level identifications were considered in this dissertation, the number of applications that it would be suitable to serve would be greatly diminished.

5.7 Scenario 6 - Registered individual, multiple mobile devices

This scenario served to test a "strange" situation. Since the part of the system being tested here is only referent to the associations made to the clients, no result graph is presented. For this test, an individual equipped with 2 Wi-Fi capable mobile devices is inserted in the coverage area of the system for the first time. This person walked around the room, having the Wi-Fi signals from both devices being detected by the respective sensors. This client was also identified by both the biometric and smart card sensors, effectively associating the Wi-Fi data in the area with the client. After these identifications and data association were completed, the client left the test area.

At a later time, the client entered the room once more, this time having one of the mobile devices turned off. Upon a second identification by either the smart card or biometric sensor, the learning mechanism came into play, removing the MAC address of the offline mobile device from the user's profile. Since this Wi-Fi identifier is now tagged as a bad association for this client, even if communications from this mobile device are detected in future visits, it will no longer be associated to the client even though it belongs to him. Only when none of the previously associated Wi-Fi identifiers are detected upon an identification of this individual (which clears the Wi-Fi data from this client's profile) will it be possible to associate this MAC address to that client again. This test served to demonstrate one of the features that the system is not currently equipped to handle, since it assumes that a client only carries a single personal mobile device. This would also be an interesting topic for future work, further improving the learning function.

6 Conclusions

Contents

This chapter draws the main conclusions that can be extracted from the work produced and suggests some points that can be improved or further developed as future work on this subject.

6.1 Main conclusions

In this dissertation, a best effort identification system was developed. This system is composed of several different sensors, each sensing a specific kind of feature, relevant for the identification of the individuals inside the sensors' coverage area. The main goal of this work was to take each of the features gathered by the sensors, correlating them in an event manager in order to produce better, more meaningful identifications, feeding applications registered in the system with personal information known about its clients.

The goal of this work was achieved, by setting up a diversity of sensors which contributed to the identifications, while keeping the system as ubiquitous as possible. As was presented in the results section, all this was possible by working with the information coming from the sensors as well as external data, such as timing, location and repeated visits by the clients. With this, the system is able to learn about its clients, leading to a more complete profile of each individual at each step. A function was also created, to place each identification made in a certain confidence range, since different sensors have different levels of accuracy when producing an action.

During the development phase, several identification methods were tested, having been detailed throughout this dissertation, allowing for an easier choice of which mechanisms to implement. This work could have been done in many different ways, producing more accurate information with lower recognition rates, or more identifications with a higher false positive rate. In the final version of this work, an intermediate solution was created, as to not limit the system too much. The confidence levels attached to every identification allow the applications receiving the information to have a better understanding of where the identifications are coming from and how much they can "trust" it.

Even though the system works as desired, providing identifications while respecting the system requirements, some limitations still exist. Things such as users carrying more than one mobile device; using a mobile device that does not belong to them; a high number of individuals close to each other being identified at the same time; among other external factors can cause disruptions in the identifications. Even if many of these incidents are covered by the learning mechanism implemented, some bad results may be generated, even if only for a little time.

6.2 Future work

With a system such as this, which works with a lot of unreliable data, many different kinds of additions could be made. The first additions that come to mind would be different sensors to either further refine and improve the data collected by the already implemented ones, or to enable new identification possibilities and a wider range of customers. Something like a Bluetooth or Near Field Communication (NFC) sensor would already open a number of possibilities.

Aside from the addition of new sensors, since the most unreliable identifications at the moment are being generated from the biometric sensor due to lack of training data, some sort of mechanism could be developed to collect a larger number of samples, either from Facebook or even using more social networks, or to further improve the facial recognition mechanism by adding some more pre-processing techniques to each image.

One thing that could greatly improve the confidence level of each identification would be the addition of a human sensor. A scenario where an employee would have a computer screen that displayed the identification information being generated at each time would allow the employee to confirm the identification of a given person through a simple interface, leading to much higher confidence information.

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