Abstract

The main aim of this project was to build an application for allowing users to track their medical records as they recorded from a medical device. More specifically, users will have the possibility to see their recordings in analytical form and also some more vital measurements concerning their health will be presented. Moreover, users will have the capability to choose a fitness goal and to be provided with some feedback based on their records. Our aim is a part of the grand goal of personal medicine which is the creation of a complete system for recording all aspects of our lives. We extended the Indivo platform by adding some new features on it and for our implementation we used real data from a patient's activity during a week as they recorded from actibelt®.

For achieving our goal we did the following:

- We installed the Indivo platform successfully on our computer, something which took us a lot of hours, and we defined a starting point for starting our implementation by experimenting with the source files of it. (See pages 27-30)
- Furthermore, we managed in the end, after a lot of research and interaction with many companies and research centres, to find some real patient's data for importing them in our database. (see pages 28-29)
- We implemented analytical representations of data (see page 32) and we calculated some vital measurements which were not recorded from actibelt® by combining the data we had with some methods and formulas we found through our research (see pages 33-37).
- Finally we started implementing the idea of providing appropriate feedback to users something which was created by giving the possibility to users to define some fitness goals (see pages 37-38).
- Our results, present how our application looks like and what we managed to implement in the end (see pages 40-53).

Due to the fact that this field of personal medicine is a very new one, it is certain that approaches like ours will attract the attention of many researchers in the near future with the grand goal of giving lifestyle advice to every user who shares his medical records on an application like this. So, there is plenty room for improvement both on our application and to this field and for that reason some ideas are presented in the last chapter of our dissertation (see pages 58-59).

Acknowledgements

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CHAPTER 1

Project outline

1.1 Introduction

In our days, personalized medicine plays a big part in people lives. Even if there were studies for many years, only the latest years some applications were created to allow people keeping their medical data online. Because personal medical information is very sensitive people are uncertain if they can trust an online application for keeping their records. It is very encouraging, that as technology evolves, the number of people who use these applications is increased rapidly. Moreover, many people combine the use of medical devices with online medical applications for recording their medical information. Apparently, this constantly growth of personalized medicine is going to completely change our lives and society in the next two decades.

Our project will try to contribute to this field by creating an online application which will not only display analytically some recordings from a medical device but also will calculate some other vital parameters concerning the health of the individual. Our grand goal we have in mind is to manage to convert a simple medical device to lifestyle advice. This means that we want to offer some feedback and possible suggestions to each user who uses our application in order to help him to keep his health status in his desired levels.

Our first idea was to implement an application based on open source software (Dossia) and to contribute to its security which is the most important aspect on these applications. However, after interaction with Dossia, they suggested to use Indivo on which Dossia is built and to make our work. Because this field of personal medicine is a new one, it was hard enough to define our objectives. After a lot of research both on security aspects of Indivo and other similar applications we concluded that it would be more vital if we could contribute to Indivo by making our own application. So, we decided to extend Indivo platform for completing our goal. Our wish was to use some real data from patients in order to use them for making a new application. After a lot of research and interaction with many companies and research centers, we managed to get some real data from actibelt® which helped us to implement our ideas. We have to mention, that even if our approach would be easier by implementing it as a simple web application, we decided to try to fit it in a world-leading existing platform in order to provide reliability and a high level of trust to our future users.

In this chapter we will present the aims of our project and we will define its objectives. Moreover we will give a general description of the dissertation’s outline.

1.2 Aims and objectives

The aim of the project is to build an application which will contribute to the field of personalized medicine. More specifically, we will implement an application where someone who has some health data which were recorded using a medical device, he can see a detailed analysis of them and also to see some other vital parameters concerning his health which are not recorder from this device. Moreover, he will be provided with some feedback by defining some fitness goals for improving his health status.

The objectives for meeting our aims are the following:

- Find an open sourced platform of personal medicine for completing our goal. In order to provide reliability to our project we have to use a well known platform and to extend its functionality.

- Install the platform and understand its functionality. We have to be familiar on how this platform works in order to be in position to extend it.

- Getting some real patient's data. We must find some real patient's data which would be recorded from a medical device.

- Implementation of our application. Our application contains three parts:

  1. Make analytically data representation for giving the user a well detailed view of his data.
  2. Try to find and calculate some other vital parameters which are not recorded from the device he used.
  3. Provide feedback to the user for improving his health by defining some fitness goals.

1.3 Dissertation outline

The dissertation consists of five parts.

Firstly, in chapter 2, we will present the background and the general context of the project. We will focus mostly on security aspects which is very vital for applications of personal medicine.

Afterwards, in chapter 3, we will give a detailed description of what we implemented and how. In this chapter will present all the procedures and tools which were used for achieving our aims.

Then, in chapter 4, we will present the results of our implementation. We will try to give the reader a detailed view of how our application looks like providing some further information for its results.

In chapter 5, we will make a critical evaluation of our work. We will try to be as much objective we can for giving the reader a clear understanding if our objectives were fulfilled and with what methods and what would have done for getting better results. Moreover, we will try to give some conclusions of our work.

Finally in the last chapter, we will give some ideas on extending our work for future development.

CHAPTER 2

Background and general context

2.1 Introduction

In our report we will try to define the most significant aspects of the new rising technology which allows people to share medical data online. All personal medical data are highly sensitive for many people so we will try to focus both on ethical and social issues concerning the data privacy and on security issues which are very important for ensuring the safety and the confidentiality of these data. In addition, we will present some good efforts that have been made in this area concerning the security of these applications in order to point out how crucial and sensitive is the usage of them. Moreover, we will give an overview of the Indivo platform which was used for the implementation of our application and also an overview of actibelt®, real data from which was used for achieving our goal.

Firstly, we will try to show the importance of sharing medical data online by providing some examples and also by showing statistical results of different surveys. Secondly we will try to deal with data privacy. We will focus on the main two aspects which deal with data privacy. One is the ethical, legal and social issues and we will try to point out the insecurity that many people feel when sharing so sensitive personal data and also some laws that changed through these years trying to solve this issue. The other is how data can be stored securely and keep their confidentiality. We will present some mechanisms for keeping data private and safe and also anonymously and authenticated. Furthermore, we will try to give the reader some details about the Indivo platform and actibelt® that was used in our case pointing out their importance on the field of personal medicine. Finally we will describe three popular applications which exist today and serve a lot of people and we will mention some general aspects of them.

2.2 Why people share medical data

As technology evolves, even more internet applications are created for making lives of people easier. One of them is an application which helps people sharing their medical data online with others. All these years, people hold their medical data in papers which sometimes creates problems. In many cases these data are hard to find, maybe are incomplete or there are different parts of them in different places. Electronic medical data provide a quick, shareable and up-to-date source of information [1]. In that case, everyone can access and update his data at any time something that helps him to be constantly informed about his health. Moreover, someone who shares personal medical data online with others he can compare them with some other from different people in order to have a general view if he is considered healthy enough comparing to others and for what data he may be worried about. Furthermore, anyone who wants to have his medical data online, he can authorize his personal doctor for constant surveillance of his data in order to be informed immediately for any change in any of them. In other words, the online storage of medical data and interaction between people is considered something revolutionary in our days and we can notice that this idea is adopted from many people every day.

A case which points out the importance of sharing medical data is the case of a person named Dave deBronkart [2], who had Stage 4 kidney cancer. When his doctor informed him about his problem he handed him a prescription slip. On it he'd scribbled ACOR.org (Association of Cancer Online Resources). After 11 minutes of submitting his first post, he received recommendations for top specialists, including links, from patients on the website's kidney-cancer list. After 30 minutes he received an e-mail from a member of this site who suggested him which scans might be appropriate and gave him details about interleukin-2, the only treatment at the time that resembled the cure. Now, deBronkart is known as the "e-patient Dave" and he is an online activist on sharing online medical data. Along with Dr.Daniel Sands who is the physician who helped him in 2007 to kick his cancer into remission, they created the Society for Participatory Medicine which encourages patients to learn as much possible they can about their health and also helps doctors to support them on this data-intensive quest.

2.3 Surveys and statistics

Some surveys through the last years showed us that there are a lot of people who trying to get medical information from the internet. According to a survey which took place in United States in November of 2000, 52 million people have used the World Wide Web for obtaining health and medical information [3] and access to medical information can be done through 20.000 to 100.000 health related websites [4]. Another survey which completed in March 2000 showed that 53.5% of participants had used the web for gaining medical information [5]. These results approximately 10 years ago pointed out that internet was broadly used from people who were interested in medical information. By combining these results with the results of another survey which took place in Canada five years later and concluded that 58% of people used the web for gaining medical information [6] we can see a significant raise of people who searching online health information. In addition, if we consider the rapid evolution of social networks were people can share different kind of information, it is almost sure that the idea of sharing medical data is a really good one with a bright future.

On the other hand, there is still a large amount of people who is not familiar with that idea. A survey from Columbia University in 2006 [7] which asked people if they have heard anything about Electronic Medical Records (EMR) had the following results:

Have read or heard about program	26 %
Have not read or heard about program	62 %
Not sure	12%

Figure 2.1: Results of survey [7]

As we can see from the above table only a 26% was familiar with this program. However, most of them believe that such an idea will be appealing with many benefits. More specific:

- 55% believe that medical errors will significantly decreased
- 60% believe that healthcare cost will be decreased
- 68% believe that the quality of care will be improved by reducing unnecessary tests and procedures

Although electronic medical recording seems a good idea to the majority of people, there is a 62% who believe that this idea is difficult to ensure patients privacy. Another survey which focus on privacy and if people feel that it overweight the expected benefits from this application had the following results:

Expected benefits outweigh potential risks	29 %
Privacy risks outweigh expected benefits	42 %
Not sure	29 %

Figure 2.2: Results of another survey [7]

As we can see from the table, about half of the people seemed concerned about how private their record would be kept, something which until today is the major concern for building such an application. Due to this fact, a recent study on electronic medical records use by the California HealthCare Foundation [8] found that the 15% of the 1849 adults surveyed would conceal information from a physician if the doctor had his medical records in electronic form with the ability to be shared with other groups. Also a 33% would consider hiding information. As a matter of fact, people become suspicious when they suspect that any personal data that want to be kept secret is shared with others without their permission. So, they must be persuaded somehow that the data they want will remain confidential.

2.4 Medical data privacy

A lot of people consider their personal medical information highly sensitive and they feel that the accessing of them must be strongly protected. This issue remains vital for many decades. There are many issues concerning how someone will be assured that their personal medical data will not be available for public view. As Mark Hadson, a former health insurance company employee, states: “I can tell you unequivocally that patient confidentiality is not eroding-it can’t erode because it’s simply nonexistent” [9]. By sharing medical data someone feels increasingly anxious about the privacy of their information. This is totally justified due to the fact that under current law and practices their identifiable medical data can be shared with insurance companies, researchers, government and others [10].
The main issues which deal with medical data privacy are:

- Ethical, legal and social issues
- Security issues

2.4.1 Ethical and social issues

It is obvious that anybody has the right to decide which medical data wants to share with others and which not. Medical history of each patient can include past physical status, diseases, disabilities, treatments and medications. Also some records may include material on mental health and psychological stability something that it is easy to understand that this information must remain private. In addition, some information that may be included considers demographic information such as education, employment status and marital status [11]. So, there is an atmosphere of distrust about the confidentiality of electronic medical information. A possible publication of some highly sensitive data can result to humiliation of the individual, loss of reputation and risks to financial status [12]. Sometimes someone who feels that their data don't remain totally private and he doesn't want them in any case to be for public knowledge, maybe he can start hiding information or worse giving fake information. This, of course, is something that really doesn't help the person to face and solve any medical problem he has, because anyone who wants to help him he will suggest something that will not solve his actual problem. A survey showed that 43% of people had felt that by keeping their medical records in electronic form is something that doesn't ensure them that they will be kept private against their will. Moreover, a 51% were worried about the activities of government [13].

As we know, the physician-patient relationship is confidential. This means that every sensible data or record of the patient must be kept secret. So, any physician who may want to share medical data with others must keep his patient anonymity. Except this patient-doctor relationship which remains confidential in most cases, privacy of medical data is not so clear because the current legislation differs across countries. Privacy may be conditioned in cases some information have the legitimate interest of government. In that case a patient can accept or reject the publication of his medical data. A decision like this can be taken after the patient is properly informed about the risks and benefits of such disclosure [14]. A good example which shows the violation of confidentiality is when a worker in a Florida state agency that conducts "anonymous and confidential" testing for HIV, decided that he can do something to protect people from infection. So, he downloaded the list of patient who had AIDS and distributed it to his friends encouraging them to avoid any date with someone from the list. This of course exposed thousands of people possibly wanted to keep secret his problem [15]. As we can see from the above example, Internet is the most convenient and cheapest way of distributing data. But, in any case the public who may have access to these data must have legitimate reasons to do that. For example, there may be some groups which are interested on some rare diseases or some investigators with scientific perspectives who have reasonable claims to mine the data, but they cannot mount the financial and administrative resources to access privately-held databases. So, how the conflict between use of public human data and public access can be resolved? This question remains unsolved until today [16].

2.4.2 Legal issues

All these years, different laws tried to deal with this problem and to make patients feel secure about their personal medical data. Anyone can wonder why is so difficult for our laws to be adjusted in order to solve the problem of medical data privacy. However, the answer is not so simple because like all ethical values, medical data privacy is often balanced against competing other ethical values and concerns [17]. A typical example is the American Medical Association's (AMA) Code of Medical

Ethics which begins with a clear affirmation of the privacy right and a strong prohibition against disclosures: “The patient has the right to confidentiality. The physician should not reveal confidential communications or information without the consent of the patient UNLESS provided by law or by the need to protect the welfare of the individual or the public interest” [18]. This exception which allows disclosures for the benefit of the patient or the public made many people to argue if this exception is totally canceling the rule.

On the other hand, in January 1999 the Maine legislature enacted a new tough law which prohibits the release of a patient’s medical information without his written permission and this prohibition was backed up with heavy fines ($50.000 per patient) for violation [17]. This rule had terrible results in whole society anyone for his reasons. For example, friends and relatives of a patient couldn’t learn about his medical status, newspapers told that they cannot report accident victims and the most important was that doctors could not compare notes for the same patient without his written permission and clinical labs refused to give patients their results over telephone [19]. As we can see from the above 2 examples neither the rule which gave the privacy right of medical data with an exception, nor the rule which tried to give too much privacy was able to cope with the needs of the society.

The most recent legislation on this issue is the Health Insurance Portability and Accountability Act (HIPAA) [20]. Although this Act trying to protect electronic medical data in a general framework, there are still some issues. For example, it doesn’t cover medical information which may be found in financial records, education records and employment records [21]. Moreover, even if HIPAA defines that generally access to someone’s medical records is obtained when this person agrees with that, in reality there is no other choice but accepting sharing health information in order to obtain care and insurance. So, in your information may have access:

- Insurance Companies
- Government Agencies
- Medical Information Bureau (MIB), which is a central database of medical information shared by insurance companies
- IntelliScript and MedPoint, which are databases that report prescription drug purchase histories to insurance companies
- Employers
- Justice, for Court Cases
- Other disclosures

As we can see, someone might be forced to provide some personal medical information against his will. Furthermore, HIPAA makes a distinction between

Electronic Health Records (EHR) and Personal Health Records (PHR). “An EHR is held and maintained by a health care provider and may contain all the information that once existed in a patient’s paper medical record, but in electronic form. PHRs universally focus on providing individuals with the ability to manage their health information and to control, to varying extents, who can access that health information” [22]. In our case, we focus on PHRs for which there are 3 main concerns:

1. the host’s ability to access and disclose personal medical information under specified circumstances
2. the hosting site’s security protocols
3. subpoenas

In contrast to EHRs which are designed for exclusively use by health care providers, PHRs are available to the consumer and maybe to some medical providers that the consumer has given his authorization [23]. However, in both EHRs and PHRs the HIPAA has many similarities because in both cases it has to do with medical data in electronic form.

In Europe, the European Internet Task Force published a report in 2005 for protecting online data [24]. According this report, all European countries have been recommended to:

- raise the awareness of Internet users
- apply existing legislation in a coherent and coordinated way
- develop and use privacy-compliant, privacy-friendly and privacy- enhancing technologies
- build trusted mechanisms for control and feedback

2.4.3 Security issues

Although ethical, social and legal issues remain until today the major concerns for sharing medical data, there are also some crucial security issues which make the patient who want to share their medical information to be very cagey. By the term security issues we refer not only to some unauthorized access that may someone has in personal data of someone else, but also how medical data are stored securely and under which mechanisms and how a patient can be assured that his data are as confidential as he wants.

All web applications consider their security as one of the most important aspects in order to fulfill the potential they give to users. Many of them have been the target of hackers who are trying to access their databases for getting some useful information for them or just for fun. Unfortunately, in the past there were many attacks not only on websites which were created from companies or individuals, but also some very important websites such as CNN and White House [25]. So, many people are wondering how safe internet applications are and if their personal data on them can be kept secret. The following example shows that there are ways of keeping a web application safe. An OpenHack contest which took place in October 2002 challenged hackers to break into Microsoft and Oracle Internet based web application. The Microsoft application took 355.00 hits and the Oracle 311.000 hits but there weren't noticed any theft of data. This means that these two web applications were very well secured not allowing any ambitious hacker to steal something from them. As a matter of fact, security can be guarantee that a web application will remain safe only if this application was properly implemented with all necessary security mechanisms which Microsoft and Oracle obviously do. We will try to define the main aspects concerning security providing some good techniques for keeping data safe.

2.4.3.1 Anonymity

Many people prefer to share medical data with others but they want to do that anonymously. This is a vital parameter for someone who decides to share his personal medical information. Keeping the anonymity of someone's medical data is something very difficult mostly because except medical data, a person can give some other information such as birth date, ZIP code, address and many more. Even if he didn't give his name, by combining other information, someone may detect the person if he wants. All these years many approaches tried to deal with this problem and to solve it.

A very good approach which solved this problem is the Datafly System [26]. This program interfaces a user with an Oracle server, which accesses a medical database and works as we can see in Diagram1. Datafly works by automatically aggregating, substituting and removing information where is necessary and providing only the most general information which are useful to the recipient. The anonymity level can be between 0 and 1. When anonymity is 0, this means that there is no anonymity at all and all data as it was in original database are passed to recipient and when anonymity has the value 1, the data which are passed to recipient is the most general possible ones.

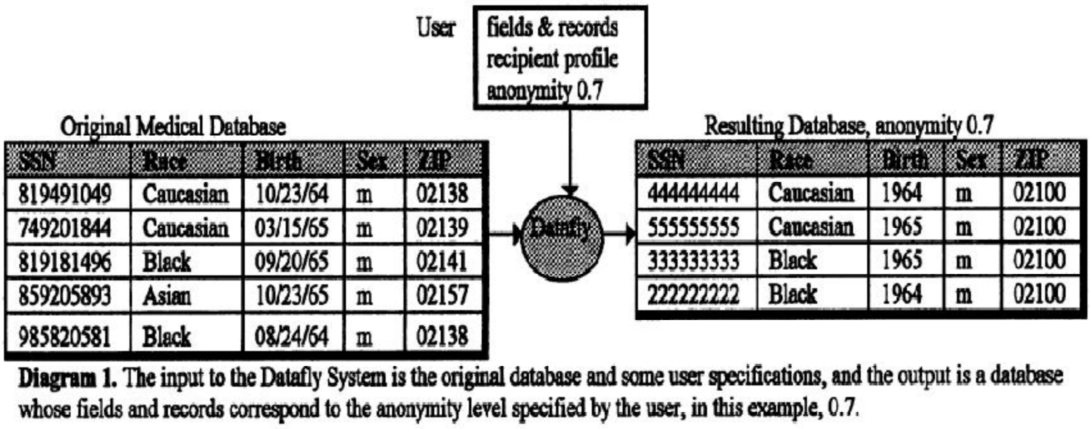

Figure 2.3: How DataFly system works [26]

Another similar approach is the μ-Argus system [27] which is a computer program that applies statistical disclosure control techniques to microdata. This program is very similar to Datafly program, but although Datafly succeeds anonymity by using generalization as the primary mechanism, μ-Argus system blanks out the outlier values at the cell-level with the cell-suppression process.
Even if these 2 systems are very effective, when data is in completely anonymous form, there is a possibility not contain sufficient details for all users, so when individuals can be identified by released data, care must be taken and enforced by procedures and policies [28].

Although these two programs seem to handle anonymity well, there are also other approaches which try to make anonymous medical data. One of them is by using one-way hashing algorithms. Two very well-known hashing algorithms which are used broadly are the MD5 [29] and the Standard Hashing Algorithm (SHA) [30]. With the use of hashing on someone's name and also on other information which are capable of his identification, this approach was used in France. Bouzelat et al. [31], [41] standardized a protocol for coding name using SHA one-way hashing. Due to the fact that there is no practical algorithm which can determine the value of the hashing name, their method was registered with Service Central de la Securite des Systemes d'information (SCSSI). However, there are some practical problems in the implementation of one-way hashes. A dictionary attack is possible which hashes a list of names and looks for matching hash values in the dataset. This attack can be avoided by encrypted the hash or by hashing a secret combination of identifier elements or both [32].

2.4.3.2 Secure data storage and authentication

A lot of people want to transfer data from and to web and there are cases that these data must be invisible to anyone else and must be stored securely. These highly sensible data such as credit card details or personal medical data somehow must be in hidden form in case a user doesn't want to be visible to anyone. Also, they must know that they can trust the Internet for keeping their data private and integral. For that reason many internet application use the Secure Sockets Layer (SSL) protocol which developed by Netscape and provides the secure transmission of a message over Internet. SSL is the standard security technology which creates an encrypted link between a browser and a web server and ensures that all data that will be passed through this link will remain private and integral. SSL is used by the majority of websites when they want to protect some sensible data of their customers [33]. SSL has three main goals:

- Secure data privacy
- Ensure data integrity
- Authenticate the client and server to each other

We will try to describe in simple words how SSL works [34], [35]

In our case, let suppose that a user A wants to send some personal medical data to a server B. So A can be assured that his data will remain confidential (privacy), cannot be altered along the way (integrity) and that these data will be sent to B and not to someone he doesn't want to (authentication). SSL relies on public key cryptography. Although in normal encryption two parties can share a key or password for encrypting and decrypting messages, it doesn't solve the problem of giving the password to someone you not trust. For that reason, in public cryptography each party has two keys, a public and a private key. Information which is encrypted with someone's public key can only decrypted with the private key. The public key is visible to anyone but each person has a different private key. So, privacy is achieved by the encryption of a plaintext to a ciphertext. More specific, when user A decides to send his data to a server B, he connected to B. B then sends A the public key in order to use it for the encryption of medical data (plaintext). After that, B has the private key with which will use for decrypting the ciphertext (encrypted medical data). For maintaining data integrity the above negotiation is not enough. Always there is a chance an attacker to receive the ciphertext which A sends to B, to alter it and to forward it to B. For avoiding such an attack we send a message digest along with the ciphertext for achieving data integrity. A message digest is a fixed-length representation of the message. Message digest is something that declares that this message was encrypted from A. The following diagram shows the mechanism of achieving privacy and integrity.

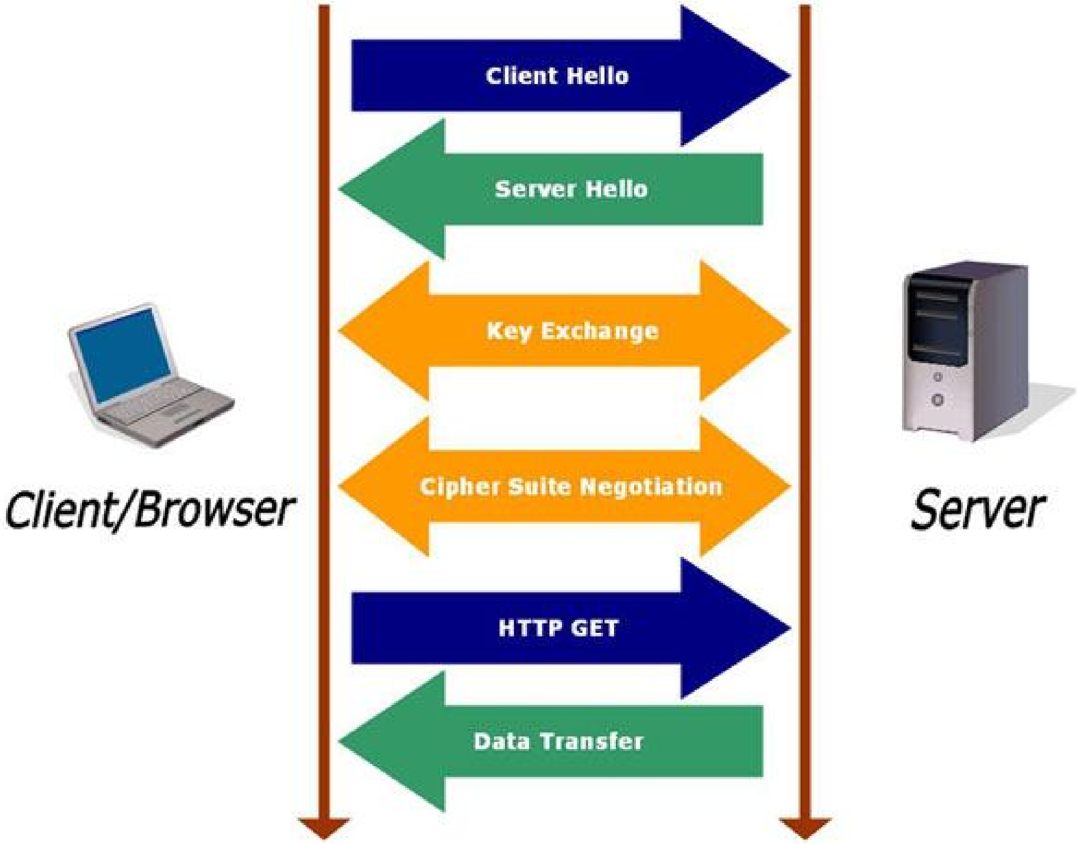

Figure 2.4: How SSL works [35]

The last goal of SSL is to provide authentication. By authentication, user A will be assured that he sends his data to server B and not to someone else. For achieving authentication SSL uses digital certificates. At the beginning of the SSL session between A and B, B sends to A a copy of his digital certificate which is an electronic document and contains information of B. Along with these information, the certificate contains also the public key of B which will be used for the encryption of data. Below we can see an example of this certification.

Figure 2.5: SSL Certificate [34]

Despite the fact that SSL is the most common protocol for ensuring the privacy, integration and authentication of online data, there are also other approaches which tried to deal with this issue.

An authentication framework for e-health systems was proposed in 2007 [36]. In this work, Al-Nayadi and Abawajy proposed a two level authentication protocol for p2p-based e-health system which provides integrated services to health care providers. The figure below describes this protocol.

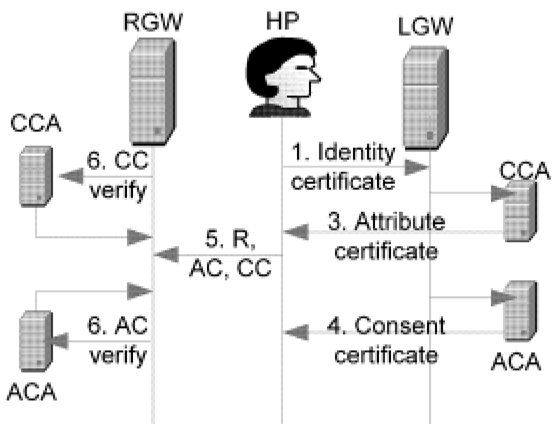

Figure 2.6: An Authentication Framework [36]

As we can see the authentication is based on three different certificates (identity, attribute, consent) which all together identify the person (HP). When HP requests for data, first is identified by the Local Gateway (LGW). After that, the GW gathers the other two certificates from The Attribute Certificate Authority (ACA) and the Consent Certificate Authority (CCA) which define the roles and accesses the user has. Then, HP sends a data request (R) to Remote Gateway (RGW) along with Attribute Certificate (AC) and Consent Certificate (CC). When RGW receive the request, sends the CC and AC to CCA and ACA respectively for verification. Verification of these two certificates authenticates the person who wants to access data. This protocol provides strong authentication and adds further confidence of security in systems.

Another good approach in sharing medical data is an encrypted search engine which implemented in NEC Labs China in Beijing [37]. The authors of this paper managed to maintain data confidentiality and access pattern privacy of a patient who authorized others to access his medical data, without any loss of them to an unauthorized person. This means that someone who wants to share medical data with someone else, he is assured that these data will be visible only to him and they cannot be accessible to someone else who is not authorized to do that. They created a prototype for the encrypted searched engine which is named Secure Public Space (SPS) and is the one we can see in the following figure.

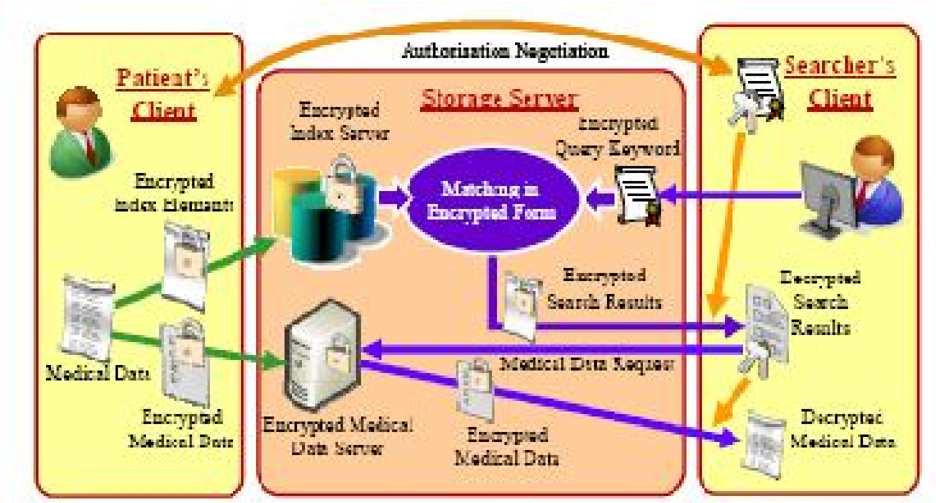

Figure 2.7: SPS prototype [37]

They ensured confidentiality by encrypting all medical with different symmetric encryption keys using AES. Every patient has his own private key and according to this key all other keys for encrypting his medical data are generated, so nobody who isn't authorized by the patient can access his medical data. Moreover, the privacy of search is maintained by the use of an encrypted keyword and a decryption key. When someone wants to search a keyword uses the encrypted keyword for searching the encrypted index. All results are decrypted on searcher's side, so nobody except the searcher and the patient knows the searching results and which keyword was used for getting them. In addition, their solution provides multi-level retrieval. Before the encryption of medical data, the patient defines the data privacy's level and then he will use the corresponding key to encrypt them in the encrypted index. Also, patient defines the privacy level of a searcher and generates the corresponding decryption key in the keyword authorization. So, the searcher's key can only decrypt information which is under his privacy level. Although this mechanism considered very reliable for someone who wants to have his sensitive medical data at an online third-party server, there are some open problem in this approach and need further research. The major problem is the conjunctive keyword search which is a common method in search engines but it is very difficult for an encrypted search engine.

2.5 Indivo

Indivo is the original personally controlled health record (PCHR) system. A subset of PCHR enables an individual to own and manage a complete, secure, digital copy of his health and wellness information. Indivo is a specific implementation of a PCHR that is Internet based, provides a World Wide Web interface, and is built to public, open standards with an open application programming interface (API) [38]. Its software allows the creation of a PCHR infrastructure that exceeds the requirements of the Health Insurance Portability and Accountability Act (HIPAA) Privacy and Security Rules. Moreover, Indivo is a three-tier system and its tiers are a data storage tier, a business logic tier and a user interface [39]. Its implementation focuses on high security and full transparency which is enforced with all three tiers and all technical documents, API and source code are open and freely available and accessible to the Internet.

The Indivo architecture is described on the figure below and demonstrates the sources of data, subscription agents (left), the three tiered architecture (center) and services that access Indivo server (right)

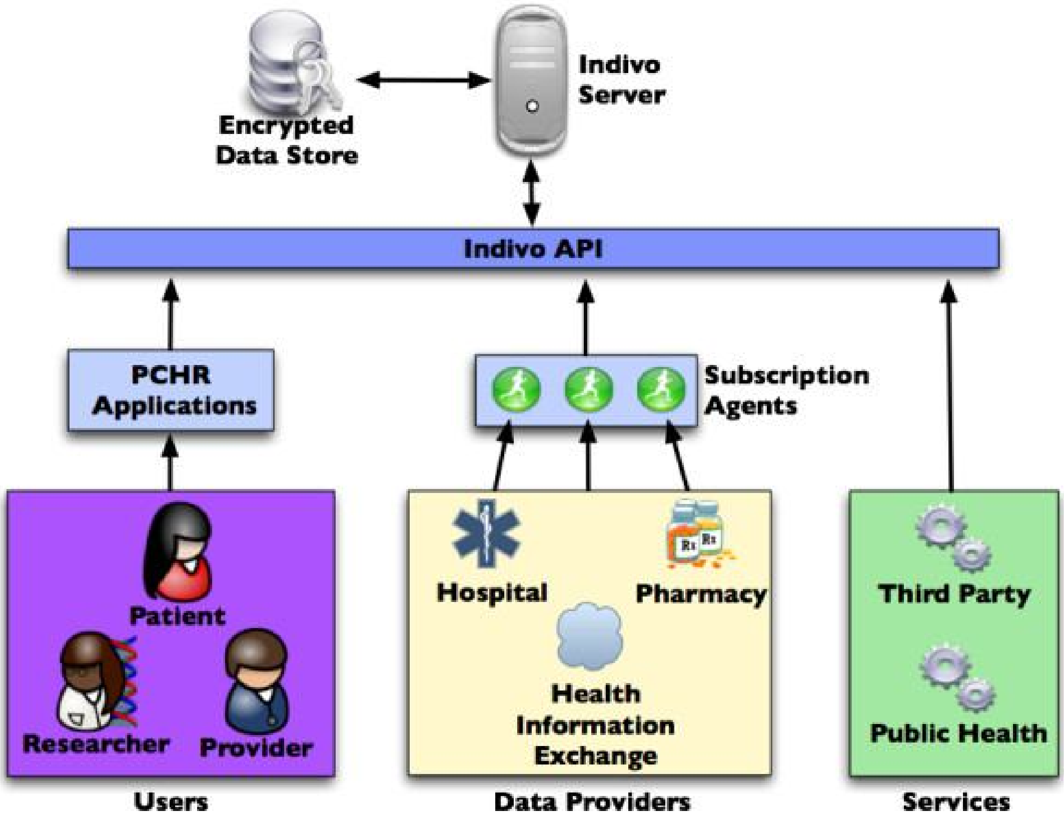

Figure 2.8: The Indivo Architecture

The core of Indivo Platform is the middle tier (the business logic tier) which is the Indivo Server. The Indivo Server is responsible for the management of the set of documents that make a PCHR record. A document within PCHR may represent a laboratory test, medication, allergy or other piece of relevant healthcare information. The Indivo Server makes these documents available to client applications via the Indivo API. The data storage tier is used by Indivo Server for storing the various data documents that make up a user's PCHR. The data storage is encrypted for protecting users and encryption keys are hosted on a separate physical server to preserve security of patient data. The user interface tier as is shown in Figure 2.9 represents the data contained in a patient's record in an understandable way. Because this graphical user interface (GUI) obtains all data from Indivo Server, any action which tries to perform is passed from the middle tier via the API and thus security policies automatically applied. Due to the fact that GUI is designed as a client that uses an open API, the Indivo approach allows others to create their own user interfaces and encourage the application development on it.

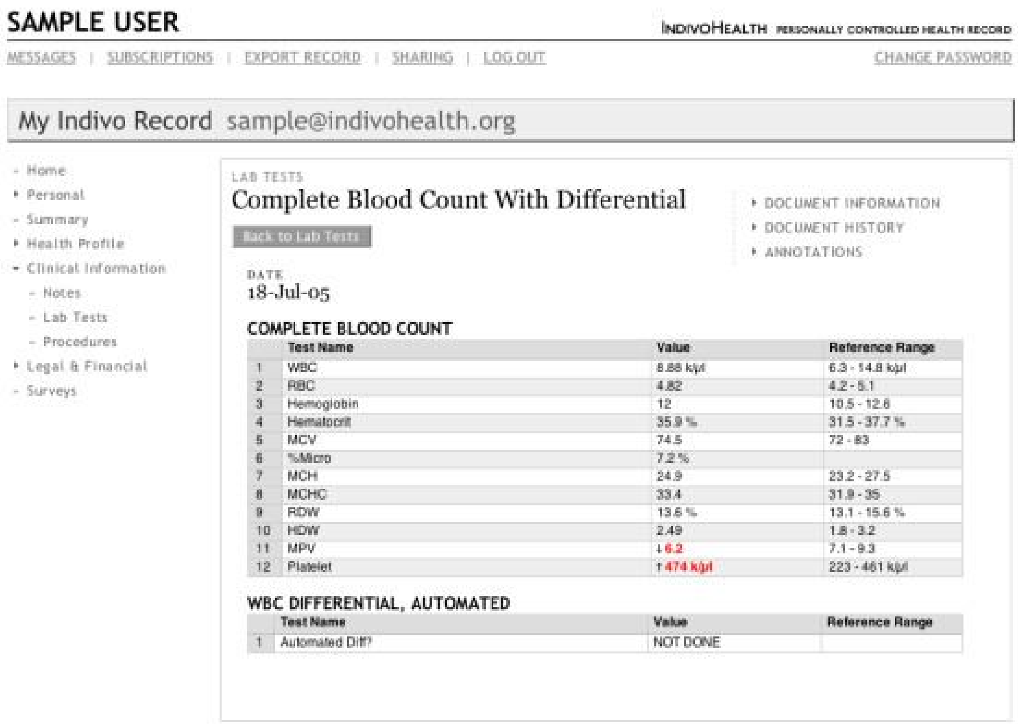

Figure 2.9: The Indivo user interface showing laboratory test results.

For the communication with the Indivo system, standard web protocols are used. The interoperability of PCHRs with electronic medical records (EMRs) and other information systems is achieved by the use of standardized methods for importing and exporting data. Indivo handles both Continuity of Care Record (CCR) and the Continuity of Care Document (CCD) for information transfer and works with the Healthcare Information Technology Standards Panel (HITSP) on interoperability [40]. A mechanism called "subscription agent" is used for importing data from EMRs and other sources [38] An important characteristic of Indivo system is that its architecture is document-centric which means that the document model is adapted for information needed by patient-centric applications and does not simply wraps electronic health data. This model is open sourced and by its use, individual autonomy is achieved in the control of information flows both in and out of the PCHR and across a health information exchange.

Indivo focuses on proving the utility of the PCHR as a platform for the development of patient driven applications to improve the quality and the effectiveness of the healthcare system. A platform like this which is built on a fully open API and standards, by providing patient-led security and aggregated data, enhances the development of an ecosystem of personalized healthcare applications. The latest years many researchers used the Indivo platform for building PCHR applications and one example is the McMaster University which developed such an application with the name "MyOscar" which not only utilizes the Indivo API but is built using the Indivo code base. Furthermore, researchers at NTIU in Norway also used Indivo for the Norwegian health system[41].

2.6 actibelt®

actibelt® is a novel platform which captures and analyses human motion and is a joint development of Trium Analysis Online GmbH and SLCMSR in Munich, Germany [42]. More specifically, is a high-tech 3D-accelometer hidden in a belt buckle which objectively quantifies walking impairment. actibelt® measures high-resolution (noise < 0.01 g, 100Hz in three axis) long term (10x24x7, 512MB) accelerations close to body's centre of mass. Its recharging is done within 2 hours using USB chargers at the clinical centre or the central lab. Moreover, by using different belt sizes and styles, different options for belt buckles (metal buckle or flex buckle) and small weight and size, actibelt® achieves a very high user acceptance and its usability aspects are very important for sufficiently long, unbiased recording times.

Figure 2.10: actibelt® usage

A well known problem so far is some invalid outcome measures in a variety of chronic disabling diseases because the level of a patient's walking ability or impairment is usually measured by using questionnaires. Physical activity in general and walking ability (distance, speed, quality) in particular play a major role as patient-oriented outcome measures in a broad range of diseases like multiple sclerosis. For that reason, actibelt® uses innovative algorithms for extracting a variety of meaningful and relevant parameters from the data which are recorded. Parameters that can be extracted from a 7-day recording include:

- activity count (one mean filtered acceleration value per minute)
- activity regions (high, medium, low)
- activity temperature (mean activity per day)
- number of steps in any given period of time & distribution (high accuracy, also at low speed)
- distance travelled & distribution (less than 15m, 50m, 100m, 200m, 300m, 500m, < 5% accuracy)
- gait speed (high accuracy – >90% of the time accuracy less than 0.2 m/s)
- gait asymmetry (e.g. limping)
- coherence length (measure for gait quality)

- norm step (including gait phases – heel strike, toe off)
- activity pie chart (lying/sleeping, sitting/standing, walking, running)
- exercise induced energy consumption (body weight needed)
- number of falls (online fall detection in preparation)
- changes in altitude/stair climbing (precision <0.5m, in preparation)

The actibelt® platform is in use in various international (AU, AUS, CH, CZ, ESP, FI, FR, GER, IT, UK, USA) multi-centre trials and clinical-epidemiological studies in multiple sclerosis, CAD, osteoporosis, lupus, osteoarthritis, Parkinson's disease, depression, schizophrenia, fracture heeling, COPD, sport and space science. Hundreds of patients, including children and elderly people, have been equipped with the actibelt®, more than 25.000 hours of recordings have been stored and analyzed. An easy-to-use web-platform supports central data management, analysis, reporting and can be linked to any eCRF-system/eTrial software with standard web-interface (in particular Trium's CT-Engine® [43]).

2.7 Existing applications for online medical data

Today there are a lot of applications which offer the possibility to someone to store his medical data online and probably to share them with other people. Despite the fact that most of them do not provide the desirable reliability and security mostly from technological aspect of view (not secure and confidential data storage and share) [37], a lot of people choose them for keeping their data. The latest years even more applications are presented providing new characteristics each time. This fact shows how important these applications are considered from the community and the significance of their existence. Moreover, when huge names in computer industry like Google and Microsoft are involved in this area and spend a lot of money for providing competitive applications for personal health information, it is easy to realize how crucial is this area and that is there is a bright future for applications like these. In addition, until today there isn't any totally trustworthy application in its completed form something which points out that there are a lot of people in community who try to provide a perfect solution. Google and Microsoft provide today two pilot projects and they hope that they will receive a global acceptance by the majority of people. Furthermore, in USA, Dossia provides an application like this which is based on open source software instead. We will present these three applications which are used broadly nowadays by millions of people.

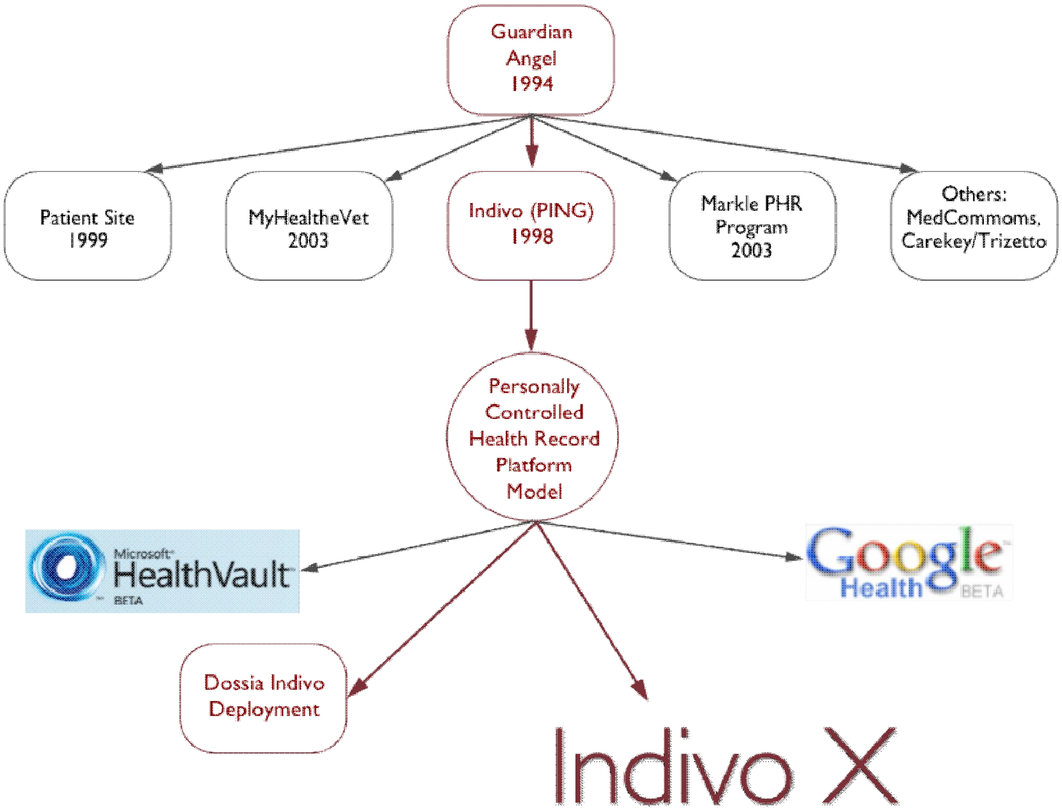

Figure 2.11: History of the Personally Controlled Health Record

2.7.1 Google Health

Google Health [44] was released in 2008 and is a service which allows users to have their personal health information online. This service provides the storing of someone's health information in a central place to make the handle of them easier. This means that any loss of his medical records due to a move or a change in his job is now prevented. Moreover, by using Google Health the user can keep always his doctors up-to-date and also he can share information with relatives, friends and some health care providers. More specific, Google Health provides the following services:

- Building of online health profiles
- Import of medical records from hospitals and pharmacies
- Sharing of personal health records
- Exploration of online health services

While building an online profile a user can enter health information such as past and current medications, allergies and test results or whatever else he wants. Google

Health assures the user in its privacy policy that his information will remain secure and never will sell it to anyone without his consent and also points out that the security is achieved by using state of the art technologies like encryption, firewalls and backup systems.

Furthermore, Google Health gives the possibility to someone to choose any of its partners to see if there is a chance the user's hospital or pharmacy to have access to his profile and send to it his medical records or prescriptions. With this method the user always will have his data updated and also an accurate medical history. In addition, the user can select an online health service which is integrated with Google Health which will have access to his information for better management of his health needs.

Moreover, anyone can choose to share his profile with someone else. The user chooses with whom wants to share his profile and any time he can stop this sharing. By sharing his health information, for example with his doctor, the coordination of his care will be better.

2.7.2 Microsoft HealthVault

Microsoft HealthVault [45] which started in 2007 is a Microsoft's platform for storing and maintaining health and fitness information. HealthVault addresses both any individual and healthcare professionals. Anyone who has an account can store his health information. Also, someone through his account can access medical records of other people only if he is authorized to do that. Apart from sharing medical data with other people, a user can share information with programs that add data to his health records and use data from the health records to provide health information or services to him.

Another functionality of HealthVault is the capability of transferring data through devices. So, devices like heart rate watches and blood pressure monitors can send automatically the current information in someone's record. Moreover, HealthVault offers some smart health solutions which combine web applications with medical devices for helping users to maintain their health in a good level and these solutions which are offered are:

- Weight solutions for loosing or maintaining weight
- Fitness solutions for having good fitness
- Blood pressure solutions for managing high blood pressure
- Organization solutions for better organizing family's health information

- In case of emergency solutions for informing someone constantly about his health

Person data privacy on HealthVault achieved by its privacy policy which states that a user who keeps medical records decides which information can be visible by others and it doesn’t release any personal data to nobody without user’s consent. In addition, health information of a user is kept safe by the use of highest standards of security which involves encryption for preventing any theft, loss or damage of them.

2.7.3 Dossia

Dossia [46] is a Personal Health Record (PHR) service which is based on Open Source software and its API was released in 2009. Dossia is a consortium of top 500 US companies. Its aim is to provide to his customers medical data control for making better health and healthcare decisions. Dossia gathers users’ health information into a safe Web-based platform helping them to have a full control of their medical data. In addition, users have access to personalized health tools which help them to improve their health and to manage better their health conditions.

The health information which is held in Dossia’s database is not only user’s data which entered by him but also health data from doctors, pharmacies and labs. Moreover, personal health records of a user are portable and at always available to him despite the fact he may change employers, insurers or healthcare providers. A very important aspect of Dossia is that health records of a user are stored securely, private and totally controlled by him, something which means that in case the user wants to share some records with others, only he decides which parts of them will be visible to someone else. Also, current employers, health insurers and providers will have access to his data only with his consent.

2.8 Summary

In this chapter we dealt with some issues that concern the use of personal medical information online. We pointed out the importance of these aspects of personal medicine and we focused both on ethical and security issues for giving the reader a better understanding of using an application like this. Moreover, we gave a description of Indivo system which is open sourced and it is used from many researchers around the world and actibelt® which is a novel device which records many parameters concerning the health of the individual. Finally we presented the top three applications until today which support online medical information and are used by millions of people. In the next chapter we will describe our project and how we managed to implement our ideas.

CHAPTER 3

Project design

3.1 Introduction

In this chapter we will try to describe the design of our project. We will present some problems which had to be bypassed and techniques that were used for implementing our ideas. Firstly, we will try to give the reader a more generic view of what we implemented and how difficult it was. Secondly, we will give some details for Indivo installation which was a vital part of our project. Moreover, we will describe the data we got from actibelt®. Furthermore, we will present some general aspects of Indivo platform and how we managed to use it for building our application. Finally, we will explain analytically each operation of our application and how it was implemented. In each section it is given the name of the file which is responsible for the implementation of each operation and it is recommended to be accessed from the source code for getting a better view on the way it was implemented.

3.2 Problem Specification

As we mentioned before, the aim of the project is to contribute to the community of personal medicine by building an application which will offer some new possibilities to individuals. More specifically we will try to convert a simple device which records some health parameters (actibelt®) to a lifestyle advice. This means that a user which uses a device for recording some specific vital measurements will have the possibility to extract more vital parameters which are not recorder by it and also to be advised properly for the status of his health with the possibility to define some fitness goals and see if he is doing well on achieving them. Moreover various representations of his data will be presented for getting a better understanding of them.

For achieving our goal we decided to use the Indivo platform. This decision was made because even if the implementation of such a web application would be easier building it from scratch, the Indivo platform is a reliable system which is designed with all necessary authentication and security mechanisms and it is used from many researchers on the field of personal medicine. Furthermore, we used some real data from actibelt®, a real device that records some vital parameters in order to have more accurate results in our project.

Despite the fact that using some real data on a well-recognized and reliable platform is something that makes our project a vital component of personal medicine, there were some major difficulties and risks which fortunately bypassed. First of all, the use of Indivo platform contains a lot of technical difficulties both on its installation and its understanding of how it works because is an open project with many functionalities and a lot of files of source code. Also, there were some difficulties on finding real patient's data and there was interaction with many companies and research centers for getting some data with Sylvia Lawry Centre for Multiple Sclerosis Activities (SLCMSR) in Germany[47] finally, to be eager to share with us some of the data which are recorded from their device (actibelt®). So, although this project had a big risk factor and some major technical difficulties, in the end we manage to solve them and also to make some further research on the field of biomedicine for getting some vital parameters for our goal.

3.3 Installation of Indivo platform

Indivo platform in order to run on a computer and possibly to be used and be extended uses many tools and requires a lot of configuration on most of them. The whole process of Indivo installation was one of the most difficult aspects of this project and a lot of hours were spent on trying different methods on configuration to make it work properly. We will try to define some basic steps which were made in order to help the reader in case he wants anytime in the future to install this platform on his computer. It is vital to mention that the operating system on which Indivo platform was installed is Windows Vista.

For the installation it was used the instructions of Indivo wiki on Indivo website but these are general instructions and not too much efficient especially in an installation on a Windows operating system [48, 49]. The tools which were used and the prerequisites of the Indivo installation are:

- JDK 1.5 (Unfortunately Indivo works only on Java 5)
- Apache Tomcat Server 5
- PHP-Java Bridge version 4.2.2
- Apache 2.0 or Apache 2.2 webserver
- PHP 5.2 or greater
- phpMyAdmin
- MySQL
- All five Indivo binary files [50]

Apart from downloading and installing the above tools there are some standard steps which has to be made in order Indivo platform works correctly. We will try to describe the most important of them which are missed or are hard to understand through the standard instructions of Indivo website.
First of all, in order to use Indivo, a script must run always on background. This script is the startStore.bat which exists in indivo-iostore-berkeleydb-core-3.1-bin.tar.gz (one of the five binary files which must be extracted somewhere on your computer). This scripts runs from a command line or a terminal. To make this script works correctly you have to configure log4j and this is done by creating a file with the name log4j.properties on "/WEB-INF/classes/" of Tomcat installation and it must have the contents described on [51]. For the key store and administration creation the createKeystore.bat and the createAccount.bat scripts must executed with the desirable options and they are placed on indivo-utils-3.1-bin.tar.gz file.

After installing successfully the Tomcat server and including the JavaBridge.war file to it, for the installation of the Apache server there is extra configuration that is not included in the instructions. More specifically for the configuration of httpd.conf apart from updating the DirectoryIndex to include the index.php and the index.htm files you have to add some more commands to make it work properly (see Appendix 1). The next step is to configure the PHP which must be extracted on a new file. For its configuration first of all you must include this file on your PATH variable of Windows. Also to include the php5ts.dll and the libmysql.dll files to Windows/System32/ and Apache/bin files respectively. Moreover, as instruction mention you have to configure the package manager which is called PEAR and it is used for installing third-party tools. So, you have to go to "../PHP/PEAR" folder and to run some commands as described on Appendix 2.

Afterwards, you have to write some SQL code after installing the MySQL and the phpMyAdmin successfully. You have to login via the phpMyAdmin and to create the tables with as they are on Appendix 3 because they used from Indivo and support much functionality.
The last thing to do if everything until then is OK, is the configuration of the PHP client API (indivo-client-php-3.1-lib.tar.gz) on which you must specify the correct paths on the apiConfig.xml file. Furthermore, a last configuration must take place for the user interface on Apache server as described on [52].

At this point it is vital to mention that for the successfully installing of the Indivo platform we made a lot of research on different websites finding and understanding some techniques mostly on some difficult parts of configuration and also with a constant interaction with Indivo forum for developers [53] we finally managed to get it work.

3.4 Data from actibelt®

As we mentioned before, one of the project objectives was to find some real patient's data. We knew from the beginning that this objective would be very hard because people share medical data online with free access to everyone very rarely. The only data we found were some anonymously data from StatLib, a statistics community [54] but they proved insufficient and inadequate for our project. Moreover, we asked Professor Tom Gaunt from the department of Social Medicine at University of Bristol if there are some data available for our research but unfortunately there weren't. So, we started the interaction with some companies and research centers for getting some data. The only response we had was from SLCMSR in Germany and they found our approach interesting. They presented to us the actibelt® with some details of it. After continuous interaction and with a short report which explained analytically the idea of our project they decided to share with us some real data from actibelt®.

The data we received, concern a patient's activity for the duration of one week. More specifically, these data is the outcome of the usage of actibelt® from the current patient on a 24-hour basis for a whole week. The days which are recorded are from 05-06-2009 until 11-06-2009. We received two datasets from SLCMSR. The first contains data which present information for each minute for the whole day and the other contains data with some summaries from the whole week. These data in their original form as they received can be found on the folder of the source code of the project.

The daily data consist of 3 fields. The first field (time) describes each minute of the day from 00:00 until 23:59 in "month/day/year hours:minutes" format. The second field (activitycount) is the activity counter for each minute which is an abstract measure for the amplitude of the activity obtained by applying some filters to the signal. The thresholds were obtained empirically from the analysis of many measurements. The third field (stepsperminute) describes how many steps the individual took during the corresponding minute.

The daily summaries data consists of 8 fields. The first field (day) describes each day of measurements in "month/day/year" format. The second field (meastime) describes the duration of measurements in minutes. The third field (time.inactive) describes the duration of low activity in minutes. Low activity corresponds to small movements during standing, sitting or lying. The fourth field (time.active) describes the duration of medium activity in minutes and corresponds to minutes of walking. The fifth field (time.exercise) describes the total time of high activity and corresponds to minutes of running. These regions are in good agreement with the step counter. The next field (activitytemp) describes the activity temperature. The last two fields (walkingsteps, runningsteps) describe the number of walking and running steps through the duration of the day. The distinction between running and walking steps uses the fact that running implies short intervals without ground contact.

3.5 Getting into Indivo

After the successful installation of Indivo platform, we had to understand how it is actually works and to be familiar with many functionalities of it. Like any other new platform which is installed for the first time, takes some time and effort to understand it, on Indivo we had not only to notice it's functionality but also to try to study it in depth for understanding how all these things are implemented.

Firstly, we experimented with some different applications of it. The first time you are connected to Indivo you are logged in as an administrator. As an administrator you have the following options:

1. Create new user
2. Import medical record in XML format

A new user, who can be created, can be a new administrator, a registrar, a patient, a provider or school. All you have to do is to give the username for creating an Indivo account (username@indivo.org) and the password. Moreover you have to complete some personal information of the user. In our case we are interested to create a user as a patient who can securely login and see medical information concerning his health.

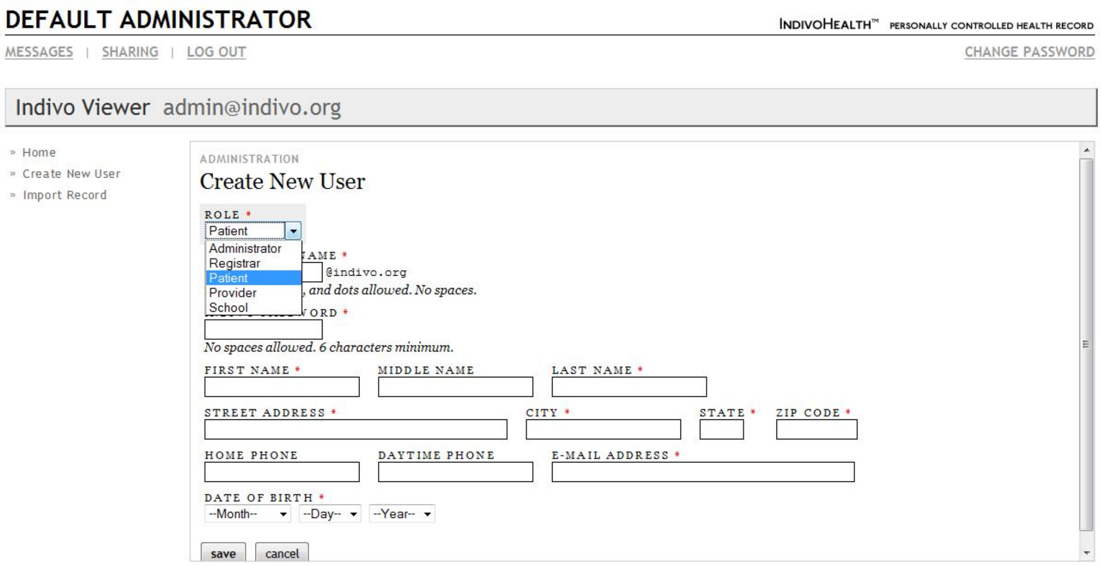

Figure 3.1: Creating new user as admin

We created a patient with the name Vasilis Tasioulas (my name) and we provided real personal information. Because Indivo offers to each patient a lot of possibilities we tried many of them to notice the interaction between them. For example, in order to see a growth chart you have to complete some demographics information including age, weight and height.

Afterwards, we tried to study the source code and to find the parts which were responsible for each operation. Apparently, a platform like Indivo uses hundred of files for achieving its functionality. After a lot of experiment with many of them we managed to define a starting point for starting writing our own application. The bad news were that almost everything were built using XAJAX programming language and because we were unfamiliar with it we had to study some tutorials for getting into the position of using it[55].

After understanding how we can use Indivo, we had to load in our database the data we received from actibelt®. In order to use them we had to import them in exactly the same format they were. So, we created 2 tables in our database, one for the daily data and one for the weekly data. The difficult part was the date fields which were in different format than the default date format of MySQL tables. For managing to load successfully these data we used the SQL commands as described on Appendix 4.

The next step on getting a complete view of Indivo was to find out how we can generate some graphs for representing the data we had. We found that jpgraph [56] was already installed on Indivo platform. Even if we were unfamiliar on plotting data using jpgraph, we decided to use it because it offers a lot of possibilities and it was fully compatible with Indivo. So, we experimented a lot by making some simple graphs in order to be in position to plot our data and to build our application. Very helpful was a tutorial we found which explains in simple words how jpgraph is used and offers some simple examples for getting started [57].

3.6 Implementation

For the implementation of our application on Indivo platform we had to add a new field on its interface which contains all our work. So, we modified the menu.default.xml file on “config/menus/” path of Indivo source code and we added the necessary tags for supporting our work and also to fit properly in the interface of Indivo. The tag which contains our functionality is called Actibelt. The user who has some data from actibelt® have the following options which are supported in separate tags of Actibelt:

- Choose fitness goal
- Show Daily MET scores
- Show VO2 max values
- Show Heart Rate
- Show Calories
- See Hourly Stats
- See Daily Stats
- See Weekly Stats

For implementing each option of the above we had to create a new xajax function in which we made the whole work for getting the desirable results. Each of these functions is called by clicking the correspondent option because they are linked with the *menu.default.xml* file we mentioned before. These functions should be separate files included in Indivo source code and they must have the file extension *“.function.php”*.

Because all these options (except the first one) result in one or more plots, we created a separate .php file for generating each graph. As we already mentioned, these graphs are generated with jpgraph, so we had to call these new files from our functions with the desirable parameters each time. The graphs we constructed are all line plots with some of them containing 2 y-axis.

We will try to explain each one of these options separately and how they are implemented.

3.6.1 Plotting the data from actibelt®

The three last options (*See Hourly Stats, See Daily Stats, See Weekly Stats*) plot the data we have from actibelt®.

The weekly stats represent the data from the table which contains the weekly summaries. More specifically, this option gives the individual the possibility to see some summaries for his data which were recorded during the whole week. The function which was created is named *weekly.function.php* and it is called by clicking the "*See Weekly Stats"* tag. It contains 8 SQL queries for getting all the data which are stored in our database. Moreover, a drop down menu was created which passes each selection dynamically as an argument to the current function in order to present the kind of data the user wants. After selecting the desirable data a jpgraph file (*lowactivity.php* or *mediumactivity.php* or *highactivity.php* or *activitytemp.php* or *steps.php*) is used with the proper parameters for plotting these data.

The daily stats represent the data of the individual for each minute for the whole day. So, the user can see a very detailed representation of his recordings. This option is implemented on *stats.function.php* of the source code. When the user selects this option, he has to choose a specific day from the whole week for seeing his recordings. For that reason, a function *"storeValue"* is called at first which creates the radio buttons for selecting the date and after clicking on an option the *"showstats"* function is called with the first argument to be the choice of date selection. The second argument of this function changes dynamically according to the selection of the hour from the drop down menu which is presented to the user. The possible values from each hour of the day could be from *"00:00-00:59"* until *"23:00-23:59"*. In that way we succeeded to plot the whole data for each minute of the selected hour of the selected date. After selecting the desirable hour, 3 SQL queries are used for selecting the proper data and they are passed as parameters to the corresponding file of jpgraph (*stepsgraph.php* and *activitygraph.php*) for plotting them. A tricky part in our queries was the correct conversion of date field of our table to an understandable format using some string functions.

The hourly stats represent the data for each hour through the whole day. This option is used to give the user a more generic view of his recordings in an hourly basis. For this option, the *hourly.function.php* was created. After selecting the *"See Hourly Stats"* tag the function of this file is called and gives the user the option to select the specific day he wants from a drop down menu. Afterwards, 2 SQL queries are used for selecting the preferable data from our database and they are passed as parameters to the responsible jpgraph file (*hourlygrpah.php* and *hourlygraphcount.php*) for their representation.

3.6.2 Calculation of metabolic equivalent (MET)

A well-known unit for describing the energy consumption through a specific physical activity is the metabolic equivalent or MET. Obviously, a physiologic effect of physical activity is that it expends energy. A MET is the ratio of energy expended during an activity to the rate of energy expended at rest [58]. The 1 MET corresponds to energy expended during rest. METs usually are calculated on an hourly basis to give a more accurate view of person's activity. Some typical values of MET, which is the result of many scientific studies, has proposed from Ainsworth et al [59].

In our project, we will try to make an approximation of MET values for each day of the week. We created the *met.function.php* file which implements our idea. Because MET values vary due to the type of exercise, we had to calculate a summary of various physical activities during the whole day. We already know 3 parameters which define approximately this type. These are the low, medium, high activity for our weekly data. The low activity minutes correspond to actions like sitting, lying, sleeping, the medium activity minutes to walking and the high activity minutes to running. So, according to tables which contain different MET values for each exercise, we make the decision to use a mean value for these three types of exercise we have. For low activity we defined 1.5 MET for each hour, for medium activity 3 METs and for high activity 8 METs. These values are the result of thoroughly study of our data and interaction with the person from SLCMSR who sent us the data. So, after making 3 SQL queries to our database for getting the total minutes of all three different types of activity, we calculated for each day the MET value from the equation:

*"daily MET value = 1.5 / 60 * minutes of low activity + 3 / 60 * minutes of medium activity + 8 / 60 * minutes of high activity"*

Afterwards, we made another SQL query for getting the date values from our database in a *UNIX_TIMESTAMP* format, because it was the only way for plotting them with jpgraph. By passing these values as parameters to the correspondent jpgraph file (*metgraph.php*), we presented the MET values to the user for each day separately.

3.6.3 Calculation of calories burned

One of the most interesting things that someone who exercises wants to know is how much calories he burned during his exercise. We made an estimation of calories the person burned through the duration of an hour for each day. For this calculation we used the weight of the individual along with the distance covered in each hour. Moreover, we present the total calories he burned each day and we calculated both the person's basal metabolic rate (BMR) and his body mass index (BMI).

In order to implement the ideas we mentioned, we had to create a new function. This function is implemented in *calories.function.php* file and is called after the user select the *"Show Calories"* tag. First of all, we had to calculate the distance covered through the duration of each hour. We know that our data contain information of how many steps the individual took on each minute. So, after finding that approximately 2.000 steps correspond to 1 mile distance covered [60], we had to find a correlation of distance with calories burned. After studying and experimenting with an estimation we found, on how much calories are burned given the distance the person covered along with his weight [61], we concluded that the equation which will give us an approximation of burned calories is the following:

*"calories burned in each hour = weight (in kilograms) * 1.45 * number of steps during this hour / 2000"*

So, we made an SQL query to our database asking for a summary of steps (*SUM(steps)*) for each hour for the given day and we calculated from the above equation the burned calories for this hour. The most difficult part on getting this result was the calculation of individual's weight. At this point, we have to mention that if the user wants to see how many calories he burned he has to give his weight in kilos on Indivo demographics information. So, we created the *"getvitals"* function (Appendix 5.2) which outputs an array which contains the age, the weight and the height of the individual using some JAVA functions. After calculating the calories for each hour we made a summary to present the total calories the person burned through the whole day. Moreover, there is a drop down menu for selecting the day the user wants to see results from and after this selection and the above calculations, the calculated values are passed as parameters to the responsible jpgraph file (*caloriesgraph.php*) for making their representation.

Basal Metabolic Rate (BMR) is an easy way to make estimation for the total calories intake a person needs daily for maintaining his weight. BMR is accurate enough especially for people with average sized body. For its calculation the parameters which are used are the age of the individual, the sex, the weight and the height. BMR can be easily calculated using the following equations both for women and men:

"Women: BMR = 655 + (9.6 x weight in kilos) + (1.8 x height in cm) - (4.7 x age in years)
Men: BMR = 66 + (13.7 x weight in kilos) + (5 x height in cm) - (6.8 x age in years)" [62]

For the calculation of BMR in our program we used the *"getvitals"* function we described above, for getting the age, the weight and the height of user and along with some other JAVA function we got his/her sex. So, we only had to apply these vital parameters to the above equation to get the BRM value of the user.

Body Mass Index (BMI) is the easiest way to determine if a person is underweight, overweight or normal. BMI is very useful on estimating a healthy body weight based on the height and it does not actually measure the body fat percentage as many people think. Its estimation is based on person's weight and height using the following equation:

"BMI = weight(kg)/height^2(m^2)"[63]

For calculating the BMI in our program we used the values of weight and height as it were calculated from the *"getvitals"* function as before and applied them on the above equation. Moreover we defined the weight status of the person by comparing the result with the values from the following table:

Category	BMI range - kg/m^2
Severely underweight	< 16.5
Underweight	16.5 - 18.5
Normal	18.5 - 25
Overweight	25 - 30
Obese Class I	30 - 35
Obese Class II	35 - 40
Obese Class III	> 40

Figure 3.2: Weight definition according to BMI

3.6.4 Calculation of maximum oxygen consumption

VO2 max is a measure of the maximum volume of oxygen that a person can use. It is measured in milliliters per kilograms of body weight per minute (ml/kg/min). During exercise, the amount of oxygen a person consumes to produce energy increases. However, there is a maximum level of oxygen consumption which cannot be further increased by training harder. Moreover, some experts believe the VO2 max is a key physiological determinant of someone's performance [64]. Although a lot of studies tried to define the best method of calculating the VO2 max value, one of the best methods today is the Balke test [65]. The objective of this test is the person to try to run as far as possible in a specific amount of time (usually 15 minutes). A method for evaluating the results from this test is achieved by the following formula which was proposed from Frank Horwill in 1994:

"VO2 = 0.172 x (metres/15 - 133) + 33.3" [66]

In our project we provide the user with the maximum oxygen consumption values he got during each hour for the whole day. It is worthy to mention that when someone is resting his VO2 value is 3.5 ml/kg/min by default. We created the *vo2.function.php* file for implementing this idea. We already knew how many steps the individual took during each minute. So, we had to calculate how many metres was the distance he covered in the duration of an hour. For that reason, we made an SQL query for getting the summary of steps for each hour. It is well-known that 1 mile = 1609.344 metres.

As we mentioned before, 2000 steps correspond to 1 mile, so we calculated the meters for each hour. Afterwards, we used the above equation for calculating VO2 values (with the only difference they were calculated for 60 and not for 15 minutes) and we passed them as parameters to the correspondent jpgraph file (*vo2graph.php*) for plotting them. Moreover, as before, there is a drop down menu for giving the user the option to select the day he wants to see his VO2 values.

3.6.5 Calculation of heart rate

A very vital parameter on tracking your health status is your heart rate. By knowing you heart rate during exercise you can determine how intense your activity was. There are some target heart zones which represent the percentage of maximum heart rate the person can have and define the activity workload [67]. It is very important for the person who exercises to know at any time his heart rate results in order to try harder or to see if his results are the desirable ones. In our project we made an approximation of person's heart rates during his activity on the whole week.

The best method we found for calculating the target heart zones was by using the Karvonen formula [68]. According to this formula the individual has to calculate his resting heart rate for three days in a row. Ideally calculation of resting heart rate is when the person wakes up in the morning. Three days measurements are used for making the calculation more accurate. After collecting these 3 values their average value is used for the calculation of target heart rate zones. More specifically, the maximum heart rate is calculated from the equation below:

"220 minus your age (A)= estimated max hr (HRMx)"

Afterwards, the average resting heart rate value is subtracted from the maximum heart rate (HRMx) and this result is multiplied with different percentages. Finally, the resting heart rate is added to the above result and represents the heart rate of the individual on that percentage. For example if you want to calculate the target heart zone of 50% of maximum heart rate and you are 30 years old and your resting heart rate is 60 bpm, this is calculated as following. The maximum heart rate is 220 - 30 = 190bpm. Furthermore, 190 - 60 = 130bpm. So, for calculating the 50%, 130 * 0.5 + 60 = 125bpm.

In our project we created the *heart.function.php* file for estimating the target heart rate zones. When the user clicks on *"Show Heart Rates"* tag the function *"restinghr"* is called which presents 3 text boxes the user must complete by giving his resting heart rates for 3 days. After entering these values, the *"heart"* function is called having as arguments the resting heart rate values. The above procedure of Karvonen formula is applied for getting the target heart zones for the individual, providing some information of what each zone stands for. The values from the above procedure are passed as parameters in the jpgraph file *"heartgraph.php"* for plotting the results.

Apparently, the user would like to know how his heart rate values were, during his weekly activity. For that reason we made an estimation of his heart rate values on both an hourly basis and during each quarter of the hour for more analytical information. For succeeding the above idea, we had to find a way to calculate the heart rate from the data we already had in our database. We found that there is a correlation of heart rate with the VO2 values we described above. More specifically, A group of researchers from Denmark concluded to the equation below:

$$\mathrm{VO_2\ max} = 15\frac{\mathrm{HR}_{max}}{\mathrm{HR}_{rest}}$$

Figure 3.3: VO2 max from heart rates [69]

So, we calculated the VO2 max value of the individual by knowing the both the maximum and the resting heart rate values. Moreover, as Swain et al proposed [70]:

"%MHR = 0.64 X %VO2 Max + 37"

This means that we can calculate the percentage of maximum heart rate given a percentage of VO2 max value. In the previous section we described how we calculated the VO2 values for each hour using the Frank Horwill equation. So, we calculated the VO2 values for each hour following the procedure from the previous section and by applying these values to the above equation (where %VO2 max is the division of each VO2 value with the VO2 max from Figure 3.3) we calculated the heart rate values for each hour. These values are passed as parameters to "*heartrategrpah.php"* jpgraph file for their representation.

Furthermore, we tried to give some more analytical results to the user by calculating the heart rates during each quarter of the hour, because it is well-known that heart rate values can increased or decreased rapidly during short time intervals. We followed the above process with the only difference that we had to make some more programming for getting our values through each quarter of each hour. As before, these values are passed to the correspondent jpgrpah file (*"heartratequarter.php"*) for their representation. Furthermore, there are 2 drop down menus which interact each other for selecting both the date and the specific hour you want to see heart rates from.

3.6.6 Implementation of fitness goals

A very useful functionality in our application is the option which is given to the user to define a fitness goal and to track his progress through the duration he decides by knowing his health results. This idea is very extensible both on defining a lot of different fitness goals and how the user learns about his progress, by seeing his results or by being provided with some feedback. For getting started with the above idea we give the user the opportunity to select a fitness goal and define some of its parameters and present to him some feedback based on his weekly results from the data he have.

First of all, we had to create a new file ("*target.function.php*") in which we implemented this option. When a user selects the *"Choose Fitness Goal"* tag the *"target"* function is called which generates some radio buttons for selecting the desired goal. Unfortunately, we didn't have the time for implementing more than one fitness goals. The one which works is the "Losing Weight". By selecting this goal the *"showtarget"* function is called having the argument from the previous option of the selected goal and generates 2 text boxes where the user has to complete how many kilos he wants to lose and in how many weeks. After submitting his options the *"loseweight"* function is called which is responsible for providing the appropriate feedback to him.

We found that in order a person to lose 1 pound per week he has to burn 250 calories daily through intense exercise [71]. We know that 1 pound corresponds to 0.45359237 kilos. So, by using the user inputs (how much kilos, how many weeks) we calculated how many calories he must burn daily by exercising. As we described in 3.6.3 section we calculated the BMR and BMI values which is very important in that case. The only difference is that we calculated the BMI the user will have after completing his goal in order to know if the goal he chose is good enough for him. Furthermore, we had to calculate the calories he burned daily with intense exercise (it is different from 3.6.3 section because we now calculate only the calories he burned during high activity). We made 2 SQL queries for getting both the steps the user made during the whole week and the activity counter for each minute. Moreover, we made another SQL query for getting the total minutes of each day the individual exercised. After experimenting with our data and by interaction with SLCMSR we defined that in order someone to exercise intensely, the activity counter must have a value greater than 0.75. So, we took into consideration only the steps he took with the appropriate activity counter. In that way we calculated the total calories he burned each day.

3.7 Summary

In this chapter, we tried to explain with as many as possible details how we managed to build our application. We described both some difficult problems we had to face and how we managed to bypass them. Moreover, we described the techniques we used and the research which was made for getting the desired results of our ideas. In the next chapter we will present the results of our implementation by giving some more details about them.

CHAPTER 4

Results

4.1 Introduction

In this chapter we will demonstrate our results from the implementation of our application. We will present the plots that were generated from our work and were implemented with the help of jpgraph. Because our project is based on an existing platform and we extended it by adding our features, we will show some screenshots which were taken from our application while it was running. Moreover, some more details for explaining our results will be given for making them more understandable to the reader than maybe were from our implementation analysis. We will present our results in separate sections as we did in our previous chapter and we will show one plot or screenshot for each different result of our project. We have to mention that in order to achieve our goal we correlated the data we got from actibelt® with the personal information of the user we created because we didn't know the actual personal information of the patient whose data was given to us.

4.2 Plots of actibelt® data

In this section, we will present the data we have from SLCMSR and we will show the graphical representation of them as they implemented in the way we described in our previous chapter.

4.2.1 Weekly stats

This section presents the data which are weekly summaries from patient's activity. These data contain information about how many minutes of low, medium and high activity the patient made, how much his activity temperature was and how many walking and running steps he took each day.

4.2.1.1 Minutes of low activity

The figure below represents the total minutes of low activity of the patient (blue line) along with the total minutes of measurements (red line). As we can notice, during the most time of this week, the patient was standing, lying or sitting something which denotes low activity.

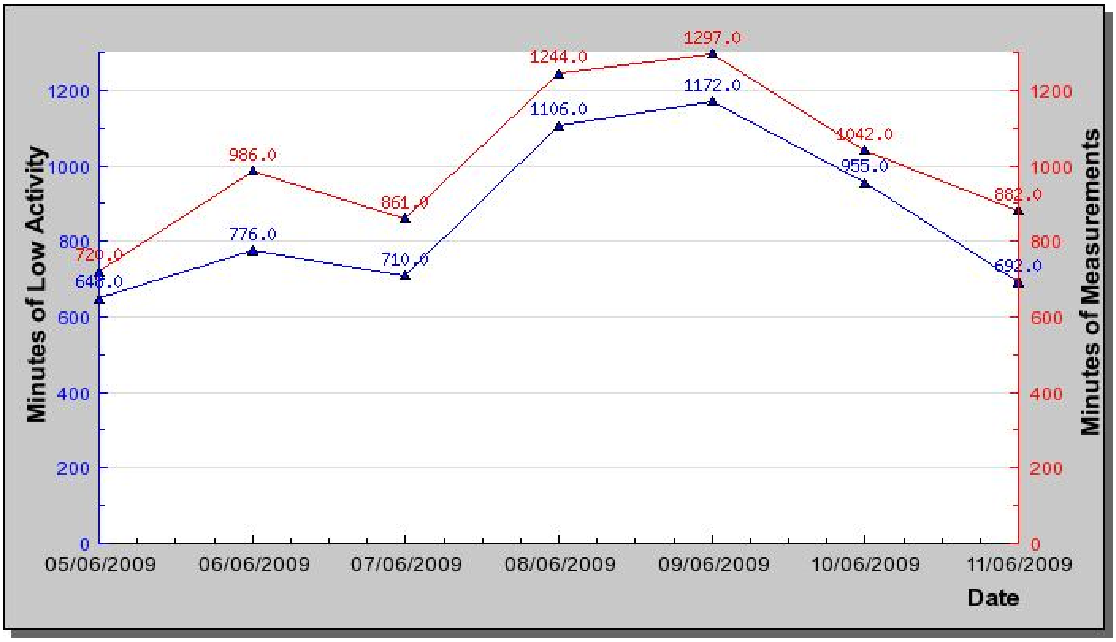

***Figure 4.1**: Minutes of low activity per day vs. duration of measurements*

4.2.1.2 Minutes of medium activity

The next figure presents the total minutes of patient's medium activity (blue line) along with the duration of measurements in minutes (red line). We can notice that the individual didn't spend a lot of hours of walking during each day. More specifically he walked the first day for about 1 hour, the third and the sixth day for about 1 and a half hour, the fourth and the fifth day for about 2 hours and the second and the seventh day for about 3 hours.

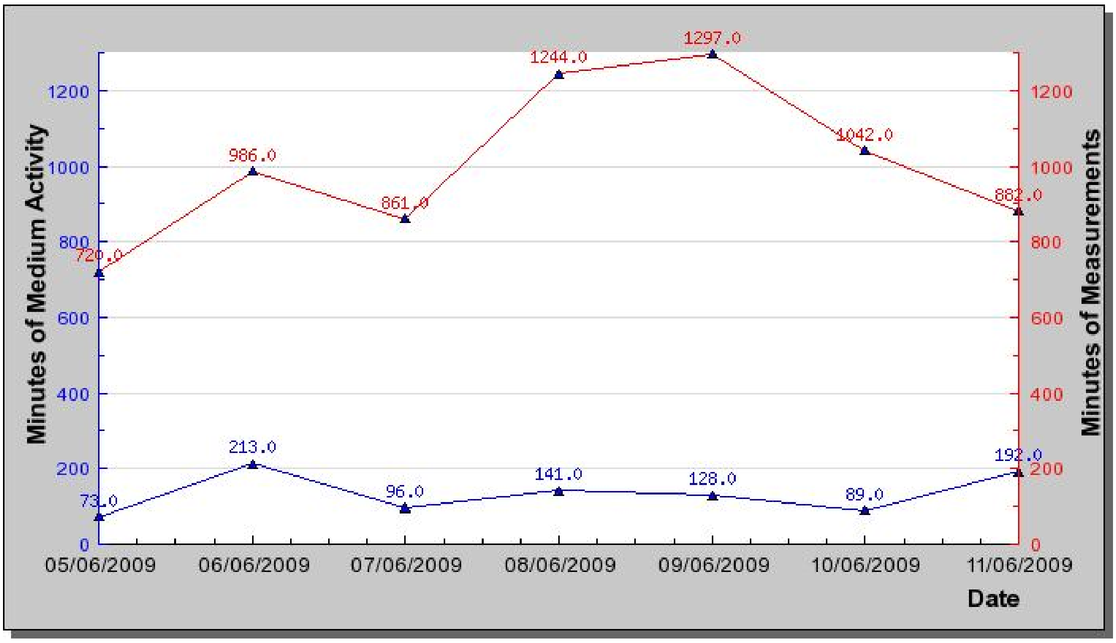

Figure 4.2: *Minutes of medium activity vs. duration of measurements*

4.2.1.3 Minutes of high activity

The next figure represents the total minutes per day of patient's high activity (blue line) along with the duration of measurements the correspondent day (red line). Apparently, the patient didn't make any intense exercise and more specifically running, through the whole week except the third day which ran for 57 minutes.

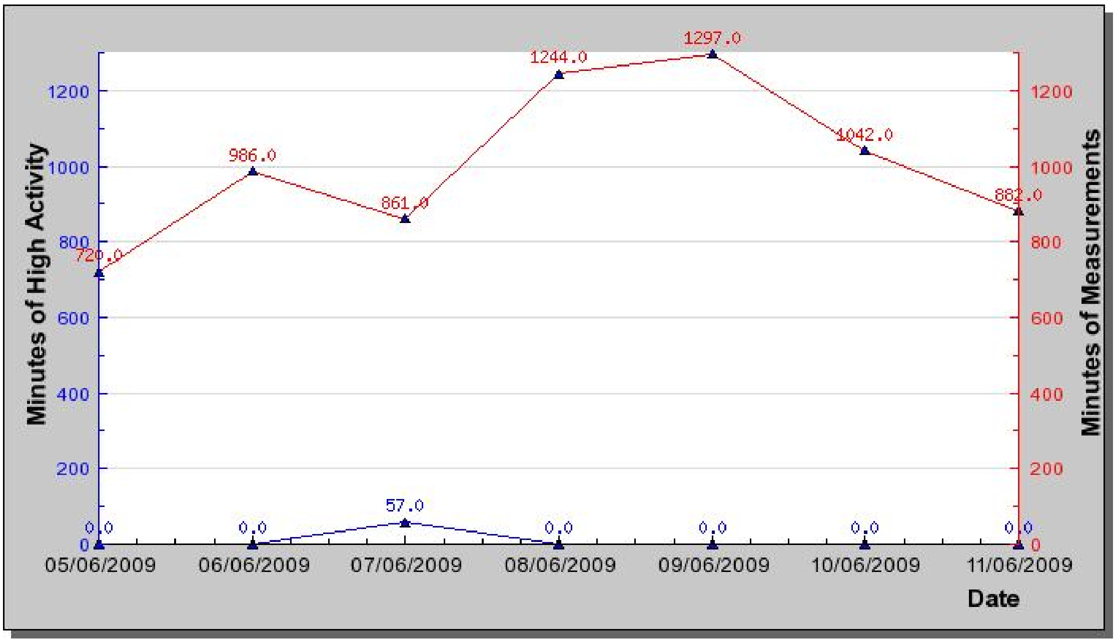

Figure 4.3: *Minutes of high activity vs. duration of measurements*

4.2.1.4 Activity temperature

The next plot describes the average values of activity temperature as it were recorded from actibelt® for the current patient. Unfortunately, no further information were given to us with some more details about this type of data, but we had to plot it because is one of the recordings of actibelt®.

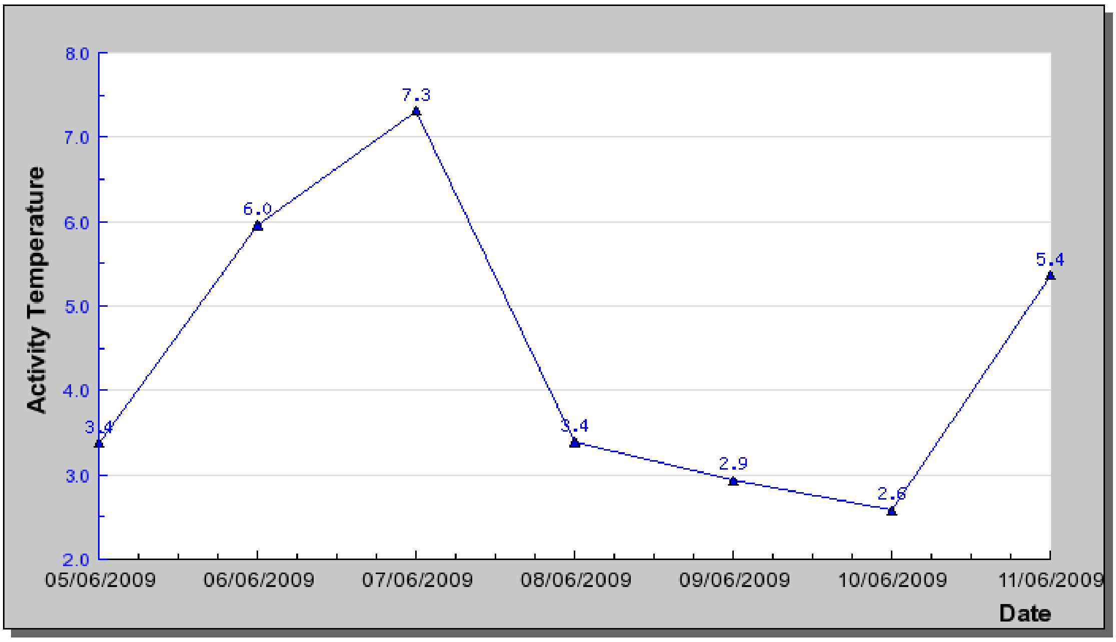

Figure 4.4: *Activity temperature average values per day*

4.2.1.5 Walking vs. running steps

The last figure of weekly stats represents the total steps the patient took during each day. The blue line indicates the walking steps and the red the running steps. As we can notice these results are in agreement with the minutes of medium and running activity because medium activity corresponds to walking and high activity corresponds to running as we described before. Moreover, we have to mention that the distinction between walking and running steps was made by measuring short intervals without ground contact in order to define the running steps.

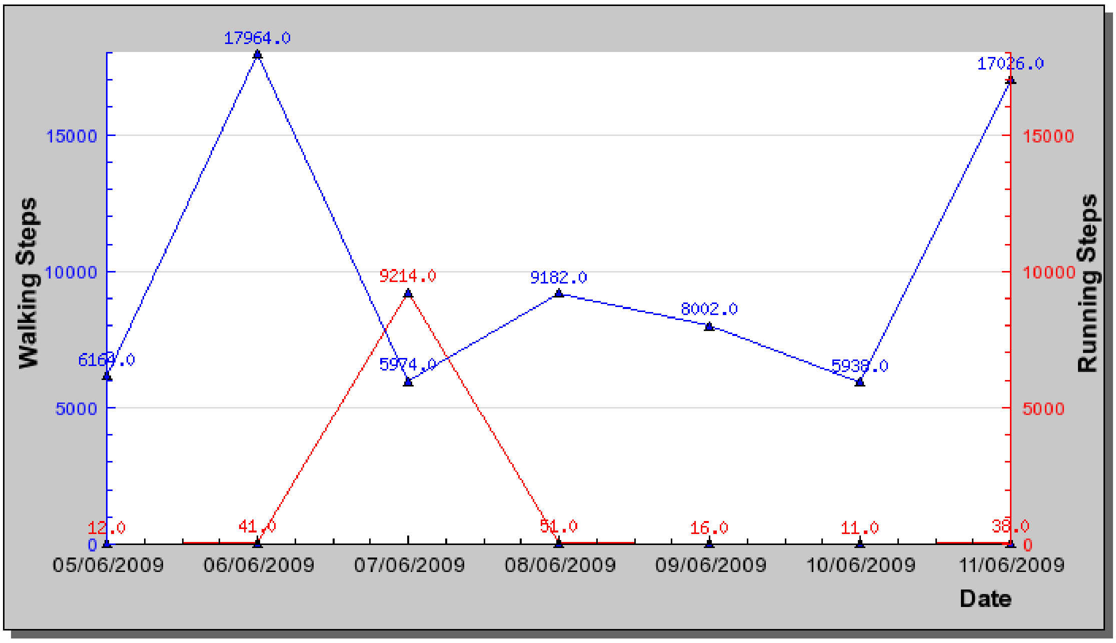

***Figure 4.5**: Walking steps vs. running steps per day*

4.2.2 Daily stats

The more analytical representation of patient's data is given in this section. His data, are represented analytically for each minute and user have the option to select both the date and the specific hour for seeing the steps he took during each minute and what value the activity counter had during this minute. The Figure 4.6 gives the option to user to select the date he wants and after selecting it the following 2 figures (4.7, 4.8) present his data as they recorded from actibelt®. During this representation of data, the user has the option to change the hour he wants to see with the help of a drop down menu which contains all 24 possible hours. Two random figures were selected demonstrating these results which represent the values from 14:00-14:59 on 09/06/2009.

Figure 4.6: *Date selection for presenting analytical daily stats per minute*

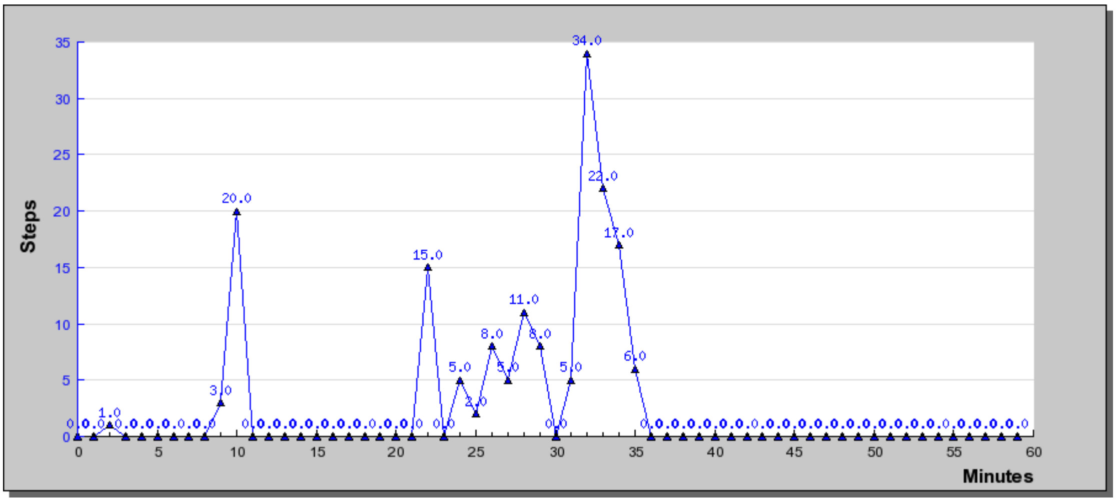

Figure 4.7: *Number of steps the individual took between 14:00-14:59 on 09/06/2009*

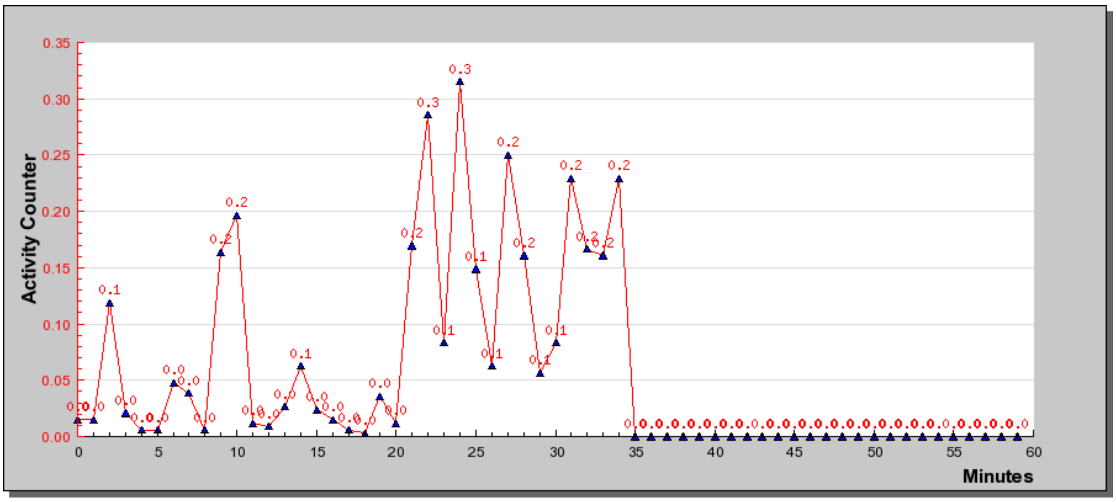

Figure 4.8: *Activity counter values per minute between 14:00-14:59 on 09/06/2009*

4.2.3 Hourly stats

The following figures present the steps who took the individual and the activity counter per hour through each day. The user can select the day he wants to see his stats from a drop down menu which presents all days from the week. This hourly representation of data gives the user a more generic view of his stats during the whole day. So, in combination with both the daily stats we described above and the weekly stats, he has a very analytical view of his recordings from actibelt®. As before, 2 figures were selected randomly for demonstrating our work.

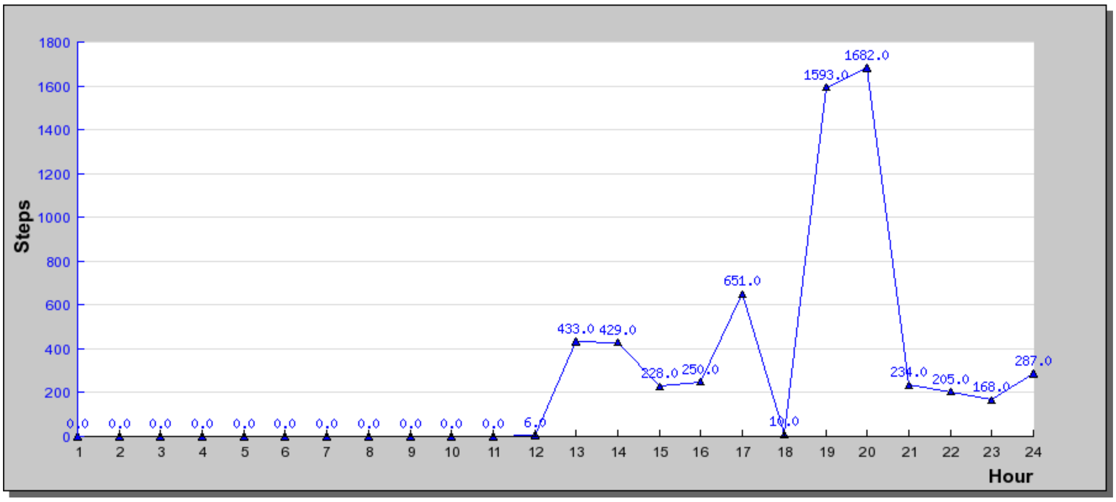

Figure 4.9: *Steps the individual took per hour on 05/06/2009*

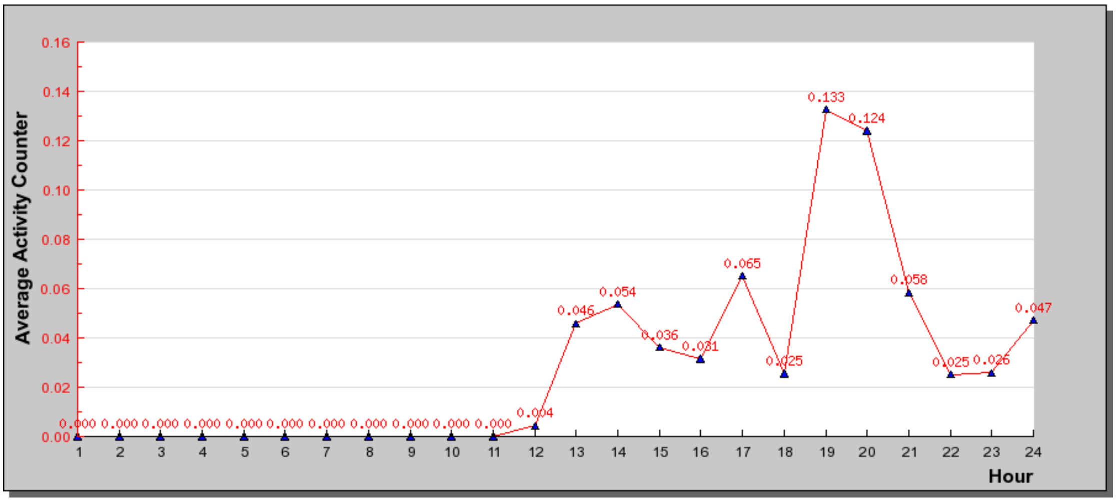

Figure 4.10: *Average activity counter values per hour on 05/06/2009*

4.3 Metabolic equivalent stats

As we described in the previous chapter, Metabolic Equivalent (MET) defines the energy which spends the individual by doing some activities. A better view which summarizes some activities and how many MET corresponds to each one of them can be found on the table which was given from The Compendium of Physical Activities Tracking Guide [59]. In our project we tried to make a summary of how many was the METs from the patient during his daily activity. We have to remind that 1 MET is defined as the energy to lie/sit quietly. So, the user can make an estimation of how much energy spent during each day separately. As we can notice from the Figure 4.11, we can see that the biggest amount of energy which was spent was during the fourth and the fifth day of the week. It is very important to notice that even if the user made intense exercise only on 07/06/2009 for 57 minutes (see Figure 4.3), he spent more energy on the next two days something that underlines that intense exercise is not enough by itself to define the amount of energy spent and it is obvious that someone who is exercising with not too much intensity but with bigger duration, spends more energy.

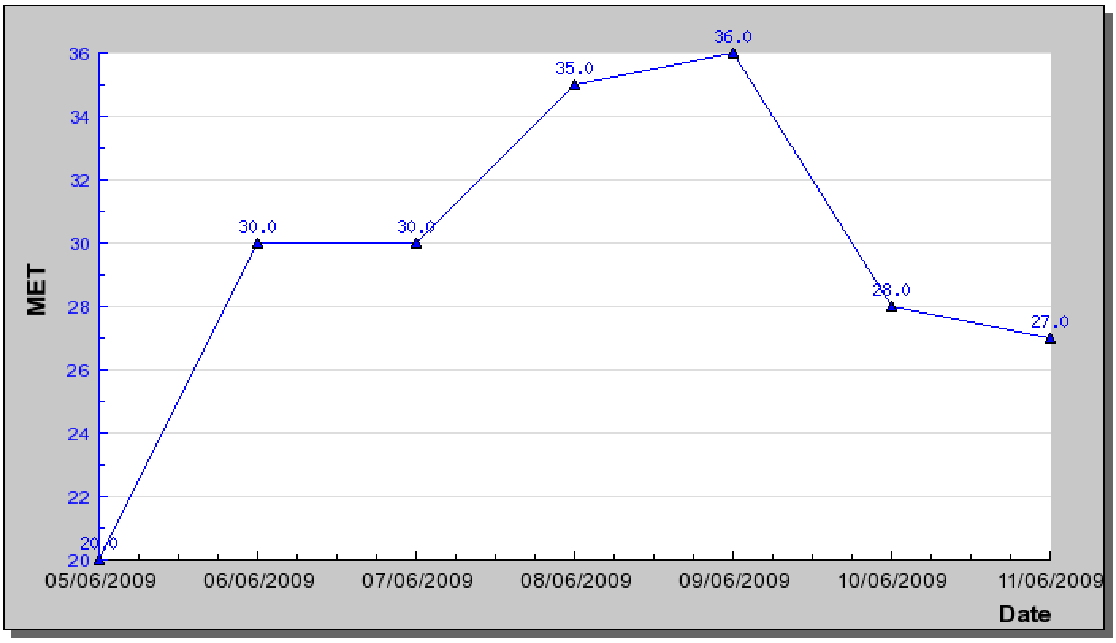

Figure 4.11: *Summary MET values per day*

4.4 Calories, BMR and BMI

One of the most interesting aspects of our project is the representation of how many calories the patient burned during his daily activity. As we explained in the previous chapter we tried to make an estimation of burned calories on an hourly basis. The Figure 4.12 below describes our results from a randomly selected date. The user can select the date he wants to see his stats from a drop down menu. We have to notice that this calculation is based only on the weight of the individual and the distance he covered (the steps he took). That’s why there are some zero values per hour something which is unrealistic because it is well known that even if an individual does not cover any distance he burns some calories. So, the zero values in our plot denote that the patient didn’t move during this hour. Also, we have to mention that we used the personal information of the virtual patient which was created (me) with the weight value to be 100 kilos, because we didn’t have the real one whose data were given to us.

Moreover, we made a summary of total calories which were burned during the selected date and also we presented the BMR and BMI values for the user which were described analytically on section 3.6.3. Because BMR uses on its calculation the weight, the height and the age of the individual and the BMI the weight and the height the values presented in Figure 4.13 concern the virtual patient only and they have nothing to do with the data we have. The value of the weight as we mentioned above is 100 kilos, the height 185 cm and the age 25 years old.

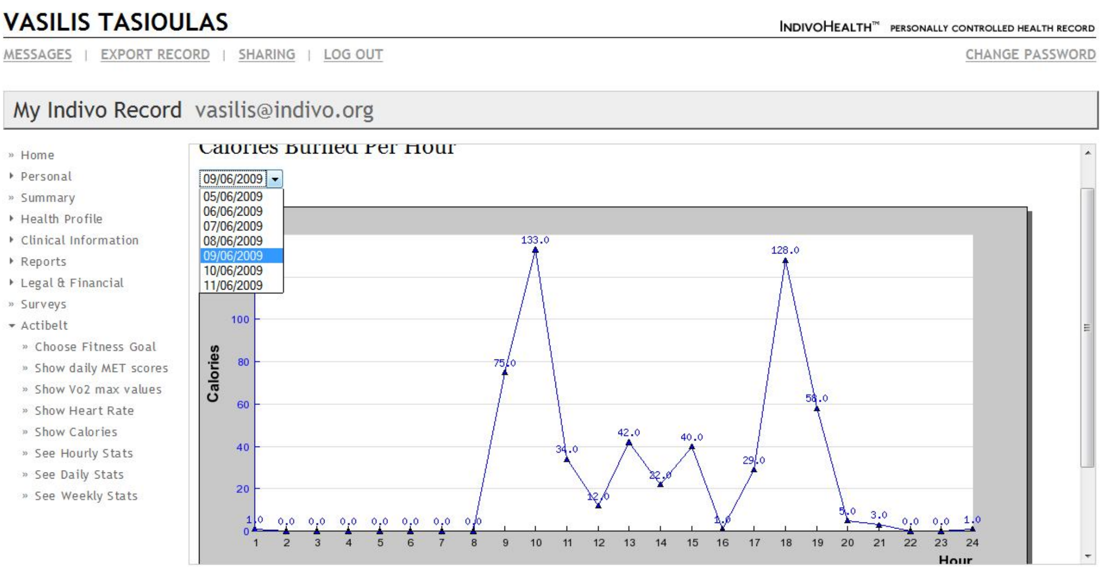

Figure 4.12: Calories burned per hour 09/06/2009

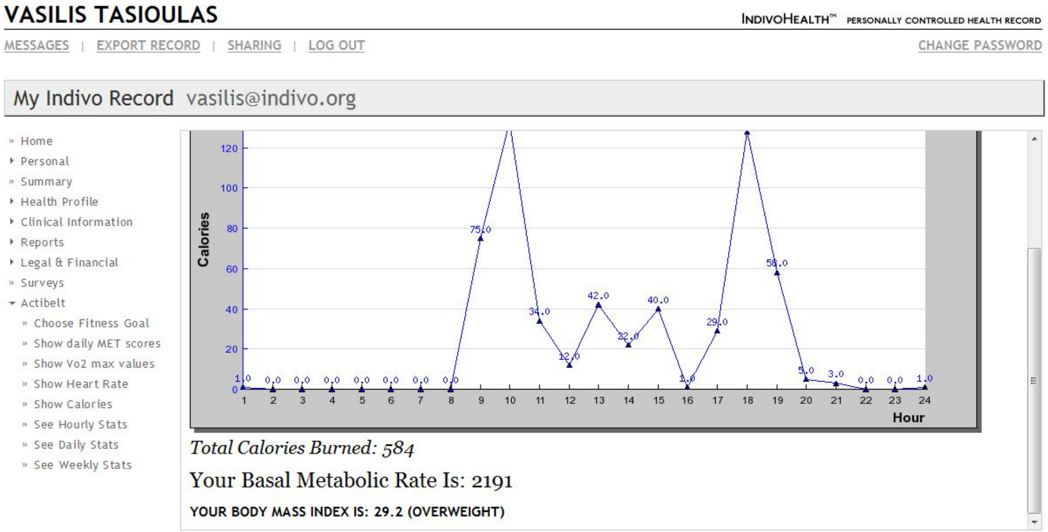

Figure 4.13*: Total calories burned on 09/06/2009 along with user's BMR and BMI values*

4.5 Maximum oxygen consumption (VO2 max)

The maximum oxygen consumption is a measure of a person's aerobic fitness. This measure is very useful for someone who wants to be informed about the intensity of his activity. In our project we tried to calculate daily average VO2 values for each hour separately. The user can select the date he wants and to see his VO2 scores per hour for the selected date. The Figure 4.14 describes the VO2 values on 07/06/2009. This date was selected to point out how the VO2 value is increased during intense exercise, because as we can see from Figure 4.3 on this date the patient made intense exercise for 57 minutes. Obviously, this exercise took place between 15:00-15:59 (the 16th hour of the day). Moreover, the value of VO2 when the person is resting is 3.5 ml/kg/min and this means that during this hour the person didn't make any physical activity. Also, someone can notice if these scores define a good level of physical activity with the help of a table which shows how good these scores according to the age of individual are [72].

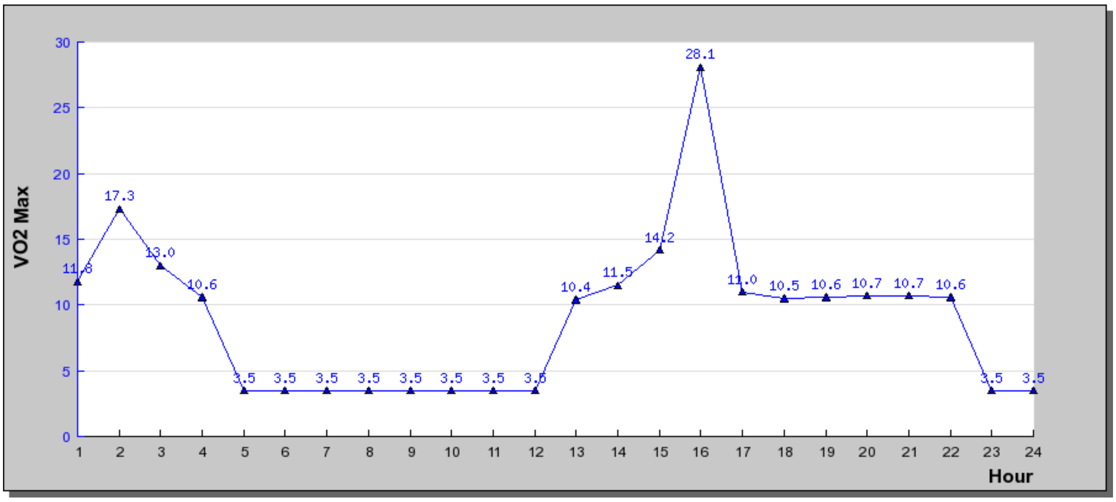

Figure 4.14*: Average maximal oxygen consumption values per hour on 07/06/2009*

4.6 Heart rates

The heart rate of a person is without any doubt a very vital measurement. That's because is the most accurate method on defining how intense was his exercise. During daily exercise, someone wants to know how his heart rate was, in order to know in the future if he has to try harder to achieve the desired results. In our project, by knowing some vital parameters from user (weight, height, age, sex) along with the distance he covered on each minute, we only have to know his resting heart rate for implementing our goal. As we described on section 3.6.5 we found a way to determine person's maximum heart rate, his target heart rate zones and also the heart rate values depending on his activity both on an hourly basis and during each quarter of the hour.

Figure 4.15 asks from user to enter his resting hear rates for 3 days. Afterwards with the Karvonen formula the maximum heart rate of the user is determined along with the heart rate zones (Figure 4.16). Moreover, there is an explanation of each target zone (Figure 4.17) in order the user to know what value should have his heart rate during exercise. For example, if the user wants to start burning fat he must training with his heart rate values to be between 50%-60% of his maximum heart rate.

Furthermore, we presented the hourly heart rates on Figure 4.18. The user can select the date he wants from the drop down menu and to see his stats. We are showing the results from 07/06/2009 because as we mentioned before, during this day the user exercised intensively for about an hour. As we can notice from the figure, during the hour of intense exercise the user's heart rate has a value of 158 bpm (beats per minute). This means that he was exercised with his heart rate to be on an average value of 70% of maximum heart rate (195 bpm), something which points out that he was training between aerobic and steady state of heart rate zones.

Additionally, we calculated more analytically his heart rate during each quarter of the hour (Figure 4.19). This approach gives a very detailed view of patient's results. We selected to show the 16th hour (15:00:15:59) on 07/06/2009 where we had the most intense exercise. As we can notice from the Figure 4.19 the actual intense activity of the patient was during the first 3 quarters of the hour with the heart rate reaching a value of 168 bpm (approximately 78% of maximum heart rate). This means that by viewing the results of a patient in a more detailed form, we can determine more accurately his actual heart rates (he trained for a long period of time with 78% of maximum heart rate instead of 70% we presented on an hourly basis).

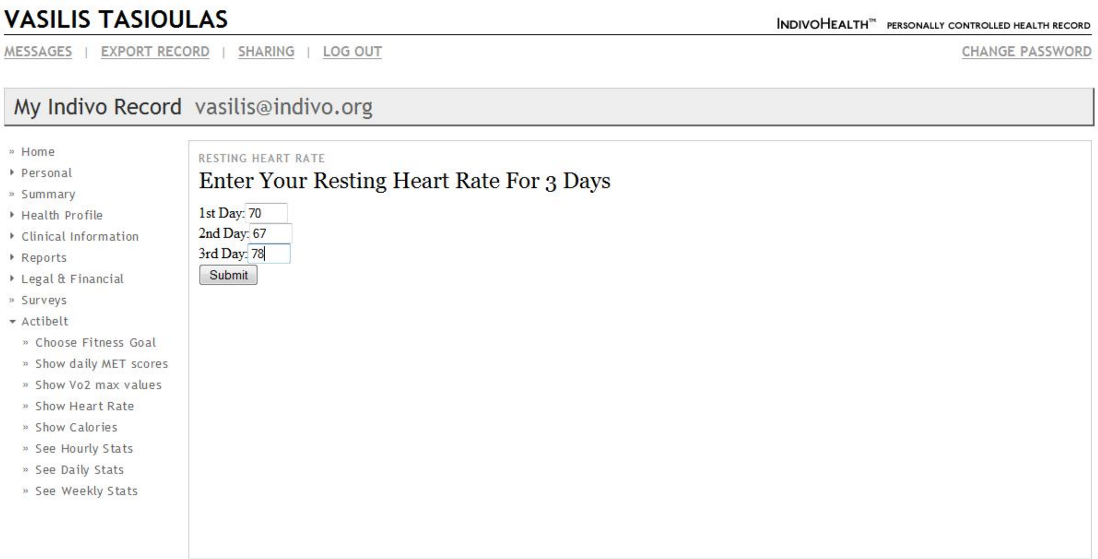

***Figure 4.15**: User enters his resting heart rates for 3 days*

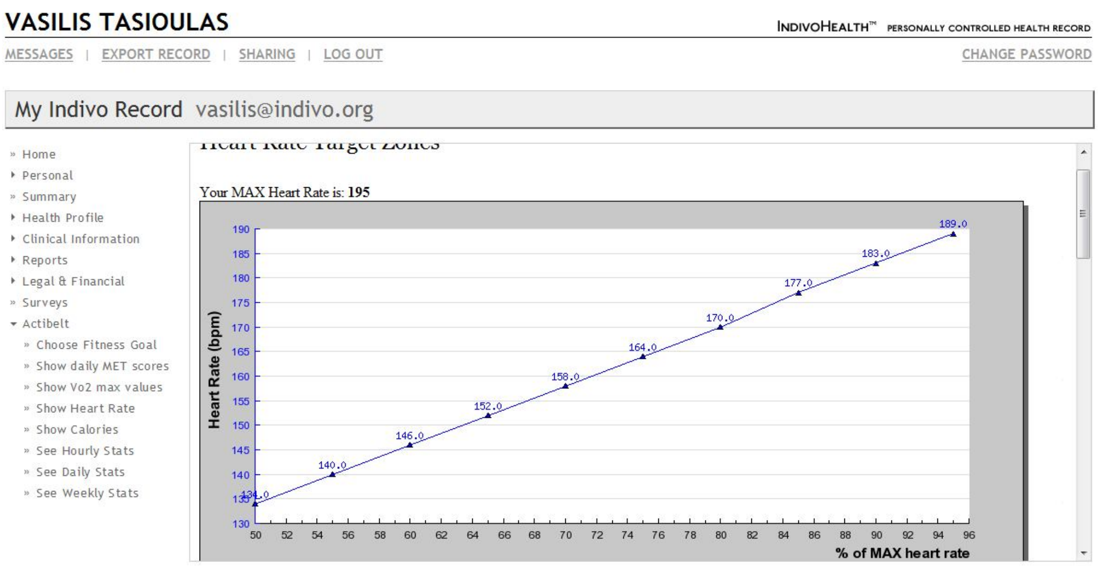

***Figure 4.16**: Calculation of percentages of maximum heart rate*

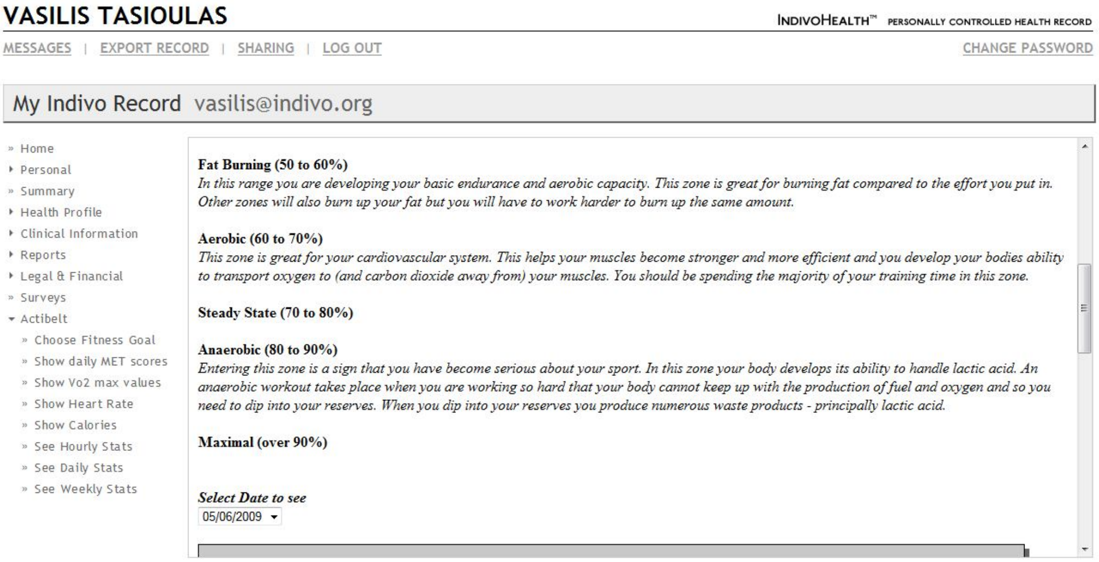

***Figure 4.17**: Information about the heart rate zones*

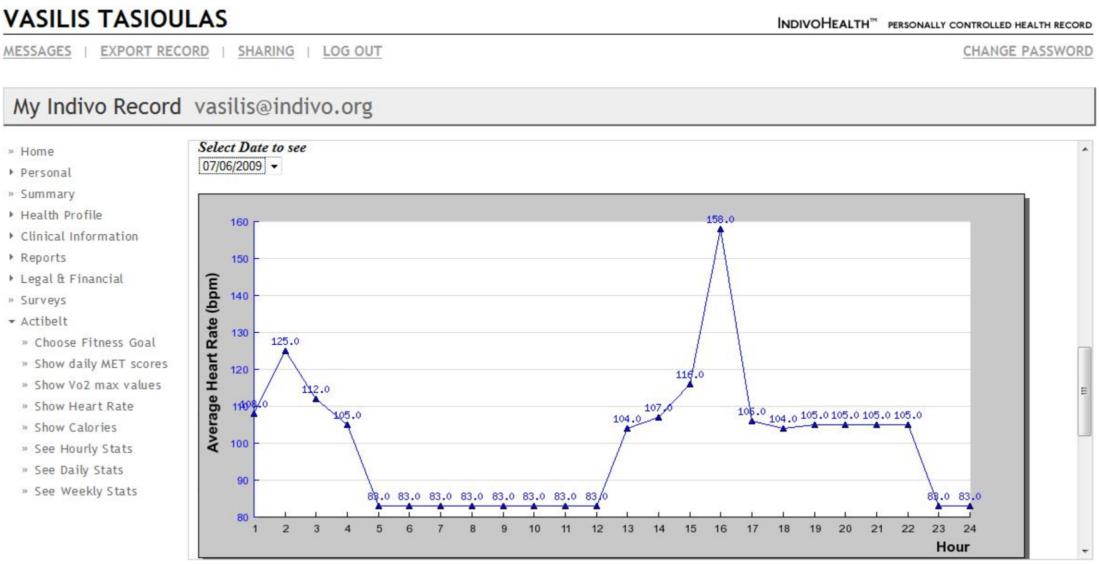

***Figure 4.18**: Average heart rate values per hour on 07/06/2009*

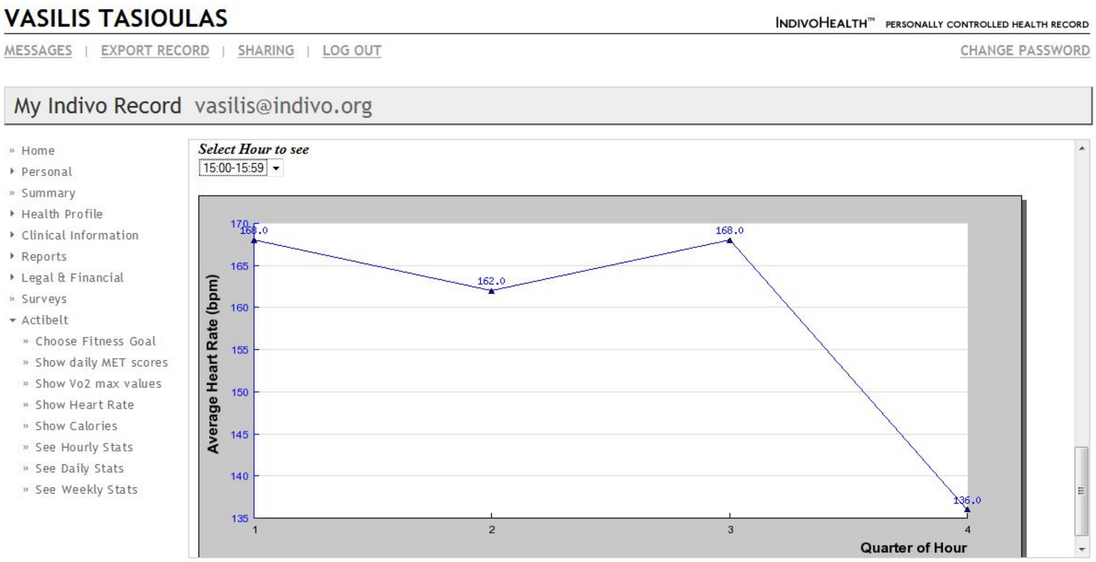

Figure 4.19*: Average heart rate values per quarter between 15:00-15:59 on 07/06/2009*

4.7 Fitness goals

One of the most important aspects of our project is the option which is given to the user to define some fitness goals and to be provided with some feedback. Due to lack of time we managed to implement one fitness goal (weight loss). After the user defining his goal (weight loss in our case) he must select how many kilos he wants to lose in how many weeks (Figure 4.20). After defining these parameters the Figure 4.21 is presented to him. First of all the current goal is determined by making estimation of how many calories he must burns daily in order to achieve his goal. Moreover, there is information of how many calories he must take daily for maintaining his weight (BMR) and how much will be this value after completing his goal. Furthermore, the current status concerning his weight is presented (BMI) which determines if the person is underweight, normal, overweight or obese and also there is the correspondent information of his future status after completing his goal. Finally, the weekly results are presented to the user which show if he managed to achieve his goal by presenting the number of calories he burned daily. Unfortunately, because we had data for only 1 week we couldn't provide any further information to the user in a goal with duration more than 1 week as you can see from our example whose duration is 3 weeks. We have to remind the reader that exercise which required on completing the goal of losing weight includes only intense exercise and that's why in our results we have 6 days with zero values (see Figure 4.3).

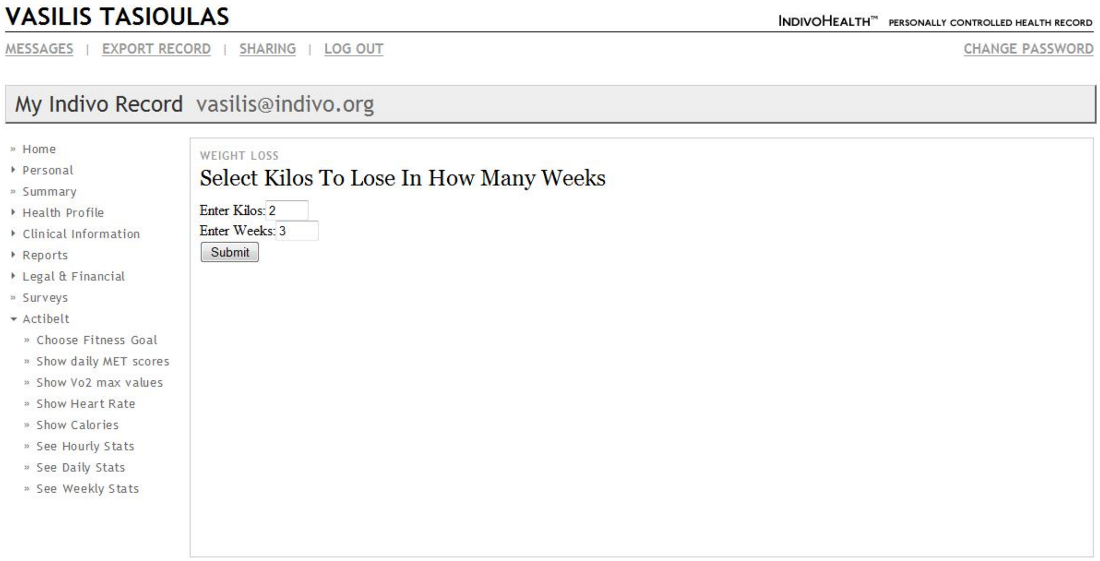

Figure 4.20: *User selects the number of kilos he wants to lose and in how many weeks*

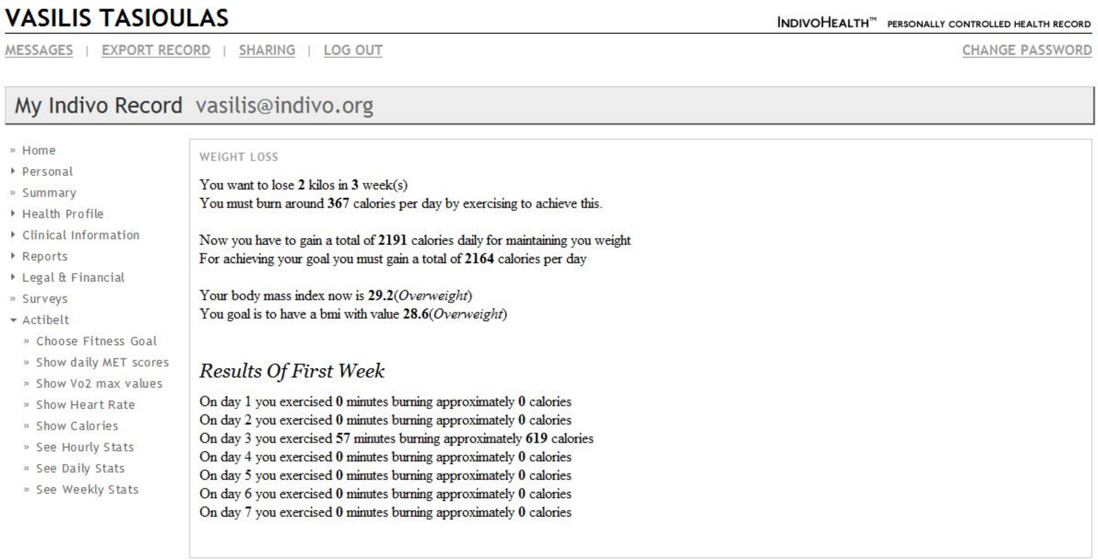

Figure 4.21: *The information which is provided to the user after defining his goal*

4.8 Summary

In this chapter we demonstrated our results from the implementation of our project. We tried to explain them with as many details as possible and to give the reader a generic view of how our application works. One figure of each different result of our project was presented. In the next chapter we will try to make a critical evaluation of our work and to describe some future work on this project because it can be extended with many new features.

CHAPTER 5

Critical evaluation and conclusions

5.1 Introduction

In this chapter we will try to make an evaluation of our work. We will explain if our project completed its objectives and how they were implemented. Moreover, we will discuss if our tools and our methods which were used, were the best ones. Moreover we will give conclusions for each chapter separately by discussing their results.

5.2 Achievement of aims and objectives

Our objectives, in general, were completed. As we said, our goal was to implement an application of personalized medicine which will give the users the possibility to see analytically their data as they recorder from a medical device, like pedometer, and to calculate some more vital parameters which were not available from this device. Moreover, our grand goal we had in mind was to provide feedback to the user and some more suggestions concerning his health through some fitness goals who defined.

First of all, our wish was to use a well-known and reliable platform for building our application. That's because we wanted future users not to be cautious about its use and they can trust it on sharing some personal medical information. The platform which was open sourced and we decided to build on it our approach was the Indivo platform. This choice was the result of interaction with Dossia which was our first candidate platform. It is obvious that by making our application from scratch would be much easier, because practically our project would be a simple web application. With the use of a new platform which is used from many researchers we contributed to its functionality by adding some new features.

After deciding to use Indivo platform, we had to find a way to use it. First of all we had to install it on our computer for starting making our work. This turned out to be more difficult than we expected because Indivo uses a lot of tools with many dependencies for making it run successfully. After trying without success for a lot of hours to setup this platform, we managed to install it after interaction with a member of Indivo forum, without the help of whom we wouldn't make it and maybe we would have to change our approach.

Another big risk in our project was to gain some proper medical data. After a lot of research and interaction with many research centers and companies we got a reply from SLCMSR, a research center in Munich of Germany. They understood our approach and presented a medical device they created in cooperation with another company, the actibelt®. After a lot of days interacting with SLCMSR trying to persuade them to send us some real data which were recorded from actibelt®, they finally decided to send us data from a patient's weekly activity.

With Indivo installed on our computer and by having some real data we had to start our implementation. After including the data to our database we had to find out how we can use them in combination with Indivo source code for making our application. Unfortunately, Indivo is implemented using a lot of files on xajax programming language. Because we were unfamiliar with xajax we had to study some tutorials in order to be in position to implement our ideas. Moreover we had to found a way for plotting the data we had along with the new vital parameters we wanted to calculate. For that reason we decided to use jpgraph which was already installed on Indivo platform but it was new to us, so we had to understand its functionality.

Our implementation is consisted from 3 parts as we mentioned in our objectives. The first part is to plot as much analytically as possible the data we had from actibelt®. The second part was to calculate some new vital parameters which were not included on these data and the last part to provide some feedback to user concerning his health progress on defining some fitness goals. Although we implemented all these three parts adding a lot of functionality, there is a lot of room for improvement because it is an open sourced application something which makes it totally extensible and also this field of personal medicine is a new one and during the next years it is certain that many people will deal with applications like this. We present some ideas for future development in chapter 6.

5.3 Project's evaluation

For our project we used some different tools and various techniques for getting our desirable results. Moreover we made research both on general aspects of applications of personal medicine and on the field of biomedicine for calculating some vital parameters. We will try to evaluate each of the above separately.

First of all, in our background research, we presented some issues both ethical and security which concern online application for sharing medical data. Moreover we presented some approaches which dealt with security aspects in order to provide reliability and trust to the users of these applications. Although this analytical description of security mechanisms seems odd to our approach, by presenting them we want to point out the importance of security on these applications, because they have to do with sensitive personal information. So, someone who isn't convinced about how safely and anonymously his records are kept, he will not share them in an online application.

In our implementation we tried to make the application to fit well on Indivo interface. That's why we decided to use xajax even if we were not familiar with it, in order to programming in the same way as the most files of source code are implemented. Moreover, we used jpgraph for plotting our results because it was already installed and configured on Indivo source files and we wanted to make a graphical representation of our results which would seem nice on Indivo GUI. Even if, jpgraph has a lot of capabilities and there are ways of making much nicer graphs, we decided to plot the results as simple line plots because we think that the design of graphs is not too important for our project. However, nicer plots can be generated in future development.

The results of our project are only our first approach to the grand goal we have in mind for a project like this. This means that even if we managed to calculate and plot a lot of them there are alternative solutions for them. More specifically, some vital parameters which were calculated like calories burned, maximal oxygen consumption, MET values and heart rates values, use some equations and methods we found on articles or the web. These methods were selected after a lot of research because we think they were the best ones for generating our results. However, maybe there are some other methods or formulas for calculating more accurate results. The general goal in our project is to give a general idea that there are ways on calculating a lot of vital parameters using some simple recordings (e.g. number of steps). A very vital aspect on our results is that, unfortunately, we didn't know the actual identity of the patient whose date we were given. So, we had to generate a virtual user for getting our goal. Definitely, our results would be more accurate if we had the real parameters of weight, height, age and sex of the person whose data we used. Finally, due to lack of time we didn't manage to go too far our last goal which was to provide some feedback to the user after selecting his fitness goal. We implemented only one goal of losing weight and we presented as feedback some values of calories with the results of how many calories he burned during the first week, because we had data only for one week. If we had data from many weeks, maybe we would have generated a more proper feedback something that will be discussed in our next chapter.

5.4 Conclusions

The main aim of our project was to contribute to community of personal medicine by making an application which will make a data analysis of a person's recordings from a medical device and will provide to this person some more vital parameters and also some feedback. We tried to implement a part of the general idea which takes a simple medical device and converts it to lifestyle advice. Moreover, we decided to use a well-known platform for building our application and to use some real patient's data for providing some real results of our application.

In chapter 2, we made background research in the field of personal medicine and we presented the most vital issues of them along with some approaches which tried to improve the security of these applications. Furthermore, we gave a general description both of Indivo platform and actibelt® which were used for our implementation. Finally, we described the top three applications until today for sharing personal medical information online.

In chapter 3, we described the whole process of implementation. We gave a general description of our approach with some possible risks and we gave some methods which were used for the installation of Indivo platform. Moreover, we described analytically the date we were given and also our tries to understand the functionality of Indivo for building our application. Furthermore, we described analytically every feature we implemented, giving some background information were it was necessary in the calculation of some vital measurements.

In chapter 4, we presented the results of our project. The majority of them ended on a graphical representation of some values. Moreover we pointed out some vital aspects on these results and we tried to give a complete view of how our application looks like.

In this chapter we made a critical evaluation of our project. We made an evaluation of the aims and objectives of our project and also we tried to evaluate our decisions on building the application based on the methods and the tools we used and the results we got.

In the next chapter we will try to make some suggestions for future work in our project because even if we managed to implement a lot of features there is still much room for improvement.

CHAPTER 6

Future work

6.1 Introduction

In this chapter we will try to give some ideas for future development. Because our project is a part of a new rising field of science, the personal medicine, there is a lot room for improvement. First, we will give some ideas for making some extensions in our application. Then, we will present some new ideas on the field of personal medicine which would be very helpful to every people.

6.2 Extensions in our project

We discussed in the previous chapter why we used some specific methods and tools for achieving our aims. Although they were seemed the more suitable to us for representing our results there is still room for improvement for getting even better results.

First of all we represented the data we got from actibelt® in 3 formats. We made a weekly representation, an hourly representation and a minute by minute representation. However, someone can focus more on the data representation by making even more plots by combining some data of them and to give a better analytical view of them to the user.

Moreover, due to lack of time we didn't focus on making some real nice designed plots for making the application looks better. The tool we used (jpgraph) offers a lot of possibilities for making professional quality graphs and someone can focus on it for generating better images than us.

Furthermore, we calculated some vital measurements which are not recorded from a specific medical device. These measurements are the result of combination of the data we have along with some methods and formulas we found though research. Apparently, there are more vital measurements that can be calculated using the current data we have. Moreover, maybe there are more accurate techniques which can use these data and to provide better results. Someone who is interested on generating more vital parameters for the user with more accuracy can focus on this area of our project.

Finally, our last objective was to give the possibility to user to select a fitness goal and to provide to him some feedback concerning his results of the first week and with some health values. Due to lack of time and because we didn't have data from more than one week, we didn't manage to provide a complete feedback to user and also we managed to implement only one fitness goal (losing weight). Further development on this area can be the definition of more fitness goals along with some more appropriate feedback which concerns the progress of a person for more than one week.

6.3 Further development

Because our project is an application on personal medicine there are a lot of extensions which can be made for adding some new features. These extensions concern mainly our last objective of our project and generally our grand goal which is to use the application to tell people how to live their lives, in a very personal way based on their own very personal lifestyle and health.

A first approach is to use a person's medical data and to give him some information about his health status with some suggestions of things he must do or to avoid for improving his health. Moreover, the application by noticing his vital measurements during exercising, can give some recommendations for making his exercise more efficient [73].

In addition, a feature can be created which will allow the user to update constantly his health status and according to his results it will define some fitness goals for improving his health. Then, the user can select a goal which will be tracked on a weekly basis informing the user if he is doing well.

Furthermore, a very interesting feature is to give the person the possibility to select an exercising program such as swimming, biking, playing football with friends and comparing his recordings from a medical device (like actibelt®) with some average physical values of this exercise to determine if this kind of exercise suits to this user and how vigorous is. Also, a good idea is this feature to support the selection of a combination of these exercises in order to provide the person which one of them is more effective for him [74].

Apparently, there are a lot more ideas on utilizing an application like ours. Apart from the above possible extensions, the general idea is the creation of a system which will change people lives in the near future. People can use this system not only for keeping their data, but also as a personal lifestyle advisor. With that system they will manage to keep their fitness in a very good level. The latest years even more scientists and researchers try to find ways for intriguing people to use applications for keeping their medical data. It is certain, that this field of personal medicine has great future and on these applications there still much room for improvement. In the future, almost everyone will keep an online medical account for tracking his health status and to keep it in his desired levels.

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Appendix

Parts of the source code

We will try to give some essential parts of source code for making the reader to understand better our implementation. Unfortunately, due to lack of space we can’t include all our source code and the reader might have to access the whole source code for understanding its functionality.

1. Modifying http.conf file for Apache configuration

We added the following lines for properly configuring http.conf file:

```
ScriptAlias /php/ "C:/Program Files/PHP"
AddType application/x-httpd-php .php .php5
Action application/x-httpd-php "/php/php-cgi.exe"
SetEnv PHPRC "C:/Program Files/PHP"
#BEGIN PHP INSTALLER EDITS - REMOVE ONLY ON UNINSTALL
PHPIniDir "C:/Program Files/PHP/"
LoadModule php5_module "C:/Program Files/PHP/php5apache2_2.dll"
#END PHP INSTALLER EDITS - REMOVE ONLY ON UNINSTALL
```

2. PEAR configuration

We had to run the following commands for properly configuring PEAR:

```
Run pear install DB.
Run pear install Log.
Run pear install Config.
Run pear install XML_parser.
Run pear install XML_util
```

3. Creating SQL tables for installing Indivo

We ran the following SQL commands in order to create the necessary tables for Indivo platform:

```
CREATE TABLE `log` (
  `LogDate` datetime NOT NULL default '0000-00-00 00:00:00',
  `LogTime` float NOT NULL default '0',
  `Class` varchar(100) default NULL,
  `Function` varchar(100) default NULL,
  `Filename` varchar(255) NOT NULL default '',
  `Line` int(10) unsigned NOT NULL default '0',
  `SessionID` varchar(45) default NULL,
  `Message` text NOT NULL,
  `Flag` int(10) unsigned NOT NULL default '0',
  `Priority` int(10) unsigned NOT NULL default '0',
  `id` varchar(13) NOT NULL default '0',
  `Ident` varchar(16) NOT NULL default '',
  PRIMARY KEY  (`id`),
  KEY `Index_Log_SessionID` (`SessionID`),
  KEY `Index_Log_Level` (`LogDate`)
);


CREATE TABLE `priority` (
  `PriorityId` int(11) NOT NULL default '0',
  `Description` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`PriorityId`)
);

INSERT INTO `priority` (`PriorityId`,`Description`) VALUES
 (0,'Emergency'),
 (1,'Alert'),
 (2,'Critical'),
 (3,'Error'),
 (4,'Warning'),
 (5,'Notice'),
 (6,'Information'),
 (7,'Debug');

CREATE TABLE `logins` (
  `userid` varchar(255) NOT NULL default '',
  `datein` datetime NOT NULL default '0000-00-00 00:00:00',
```

```
  `dateout` datetime default NULL,
  `sessionid` varchar(50) NOT NULL default '',
  `ipaddress` varchar(50) default ''
);

CREATE TABLE invite (
  inviteId     varchar(36) NOT NULL,
  toEmail                  varchar(255) NOT NULL,
  fromUsername             varchar(255) NOT NULL,
  newUsername              varchar(255) NULL,
  sentDate                 datetime NOT NULL DEFAULT '0000-00-00 00:00:00',
  newDate                  datetime NULL,
  fromEmail                varchar(255) NOT NULL,
  flag         int(10) NOT NULL DEFAULT '0',
  PRIMARY KEY(inviteId)
);

CREATE TABLE mednames (
  medname  varchar(255) NOT NULL,
  batchid     varchar(32) NOT NULL,
  PRIMARY KEY(medname,batchid)
);
```

4. Import data to MySQL database

We used the following commands for importing the data we got into our database in exactly the same format as they were given to us. We present only 2 of them. Similar commands were used for the other files of data.

```
load data local infile 'C:/2009-06-08.csv' into table records fields terminated by ', '
enclosed by '' lines terminated by '\n'  (@date, count, steps)  set date =
str_to_date(@date,'%m/%d/%Y  %H:%i:%S %p')

load data local infile 'C:/summaries.csv' into table sums fields terminated by ','
enclosed by '' lines terminated by '\n' (@date, meastime,
timeinactive,timeactive,timeexercise,activitytemp,walkingsteps,runningsteps) set
date = str_to_date(@date,'%m/%d/%Y')
```

5. Parts of source code from xajax functions

We will present some vital parts of our code for implementing our ideas.

5.1 stats.function.php

```
....

$db = DB::connect(DATABASE_DSN);

if (!PEAR::isError($db)) {

$sql = "SELECT date from records where date like '$days $time'";

 $result =& $db->query($sql);

 $i=0;

 while($result->fetchInto($row))

 {

          $temp=strstr($row[0], ':');

           $date[$i++]=(int)substr($temp, 1,-3);

 }

 ....

$objResponse = new xajaxResponse();

$objResponse->addAssign("rightpane","innerHTML",createPageTitle('ACTIBELT
MEASUREMENTS', 'Steps / Activity Counter (per Minute)'));

          $steps = join(',', $steps);

          $date = join(',', $date);

          $count = join(',', $count);
```

```
	$img='<img src="'.SITE_URL.'/resources/php-growth-charts/stepsgraph.php?steps='.$steps.'&date='.$date.'" />';

	$img2='<img src="'.SITE_URL.'/resources/php-growth-charts/activitygraph.php?count='.$count.'&date='.$date.'" />';

....
```

5.2 calories.function.php

```
....

$demo = getDemographics();

$sex = $demo->getSex()->getCode();

$vitals=getvitals(null,DEFAULT_ITEMS_PER_PAGE);

if($sex=="M"){

$bmr= round(66 + ( 13.7 * $vitals[1] ) + ( 5 * $vitals[2] ) - ( 6.8 * $vitals[0] ));

}

else if($sex=="F"){

$bmr= round(655 + ( 9.6 * $vitals[1] ) + ( 1.8 * $vitals[2] ) - ( 4.7 * $vitals[0] ));

}

else{

$objResponse->addAppend("rightpane", 'innerHTML', "<p class=\"notification\"><b>No vitals data available.</b> ".SUBSCRIPTION_TEASER."</p>");

$objResponse->addScript("fader.fadeOut();");

$api->getLogger()->log("Returning...");

$api->getLogger()->log($objResponse->getXML());

return $objResponse->getXML();

}

....

function getvitals($pageNumber, $documentsPerPage) {

$urn = 'urn:org:indivo:document:classification:medical:vital';

$indexDescriptor	= 'VitalDateIndexer';

$ohl = new OrderedHeaderList($indexDescriptor, $urn);

if (is_null($pageNumber)) {

$pageNumber = $ohl->lastViewedPage();

}

$i=0;

while( $i<$documentsPerPage ){

$documents = $ohl->getPage($pageNumber, $i);

$i++;

	if (!empty($documents)) {

		$rows = array();

		foreach ($documents as $document) {

			$vital = $document['body'];

			$nameString = '';

			$date = '';

$ageString = '';
```

```
if ($vital->isSetDate()) {

        $date= shortDate($vital->getDate()->toGregorianCalendar());

        $dateTS= convertCalendar($vital->getDate()->toGregorianCalendar());

        $ageString= getAgeString($dateTS);

        $age=substr($ageString,0,2);

}

if (!is_null($vital->getName()))

{

$name= resolveCode($vital->getName());

$nameString= $name->Display->Value;

$result= $vital->getResult()->get(0);

}

}

if($nameString=="Weight")

        $weight = java_values($result->getValue());

if($nameString=="Height")

        $height = java_values($result->getValue());

}

….
```

5.3 heart.function.php

```
….

$timear=array('00:%','01:%','02:%','03:%','04:%','05:%','06:%','07:%','08:%','09:
%','10:%','11:%','12:%','13:%','14:%','15:%','16:%','17:%','18:%','19:%','20:%','21
:%','22:%','23:%');

$i=0;

$j=0;

$steps=array();

for($i=0;$i<24;$i++){

        $db = DB::connect(DATABASE_DSN);

        if (!PEAR::isError($db)) {

                $sql = "SELECT sum(steps) from records where date like '$days
$timear[$i]'";

                 $result =& $db->query($sql);

                 while($result->fetchInto($row)) {

                          $steps[$j++]=$row[0];

                }

        }

}

$max_vo2=15*$max/$rest_hr;//Uth—Sψrensen—Overgaard—Pedersen estimation

for($i=0;$i<24;$i++){

        $metres[$i]=1609.344*$steps[$i]/2000;

        if($metres[$i]==0){
```

```
                $vo2max[$i]=3.5;
        }
        else{
        $vo2max[$i]=round(0.172 *($metres[$i]/60 - 133) + 33.3,1);
        }
        $perc_hr=0.64*($vo2max[$i]/$max_vo2*100)+37;//David Swain (1994)
        $hr[$i]=round($perc_hr/100*$max);
        }
        ....
```

6. Parts of jpgraph files

We will present parts from only 2 jpgraph files which were used for generating our plots.

6.1 metgraph.php

```
$date = $_GET['date'];
$date = split(',', $date);
$met = $_GET['met'];
$met = split(',', $met);
$g = new Graph(700,400,"auto");
$g->img->SetMargin(60,40,30,50);
$g->SetScale('datlin');
$g->xaxis->scale->SetDateFormat("d/m/Y");
$g->SetTickDensity(TICKD_SPARSE,TICKD_VERYSPARSE);
$g->yaxis->title->Set('MET');
$g->xaxis->title->Set('Date');
....
```

6.2 steps.php

```
....
$patientPlot = new LinePlot($walkingsteps,$date);
$patientPlot2 = new LinePlot($runningsteps,$date);
$patientPlot->mark->SetType(MARK_UTRIANGLE);
$patientPlot->value->show();
$patientPlot2->mark->SetType(MARK_UTRIANGLE);
$patientPlot2->value->show();
$patientPlot->value->SetColor('blue');
$patientPlot2->value->SetColor('red');
$patientPlot->SetColor('blue');
$patientPlot2->SetColor('red');
$g->Add($patientPlot);
$g->AddY2($patientPlot2);
$g->Stroke();
```