Czech Technical University in Prague
Faculty of Electrical Engineering

Master’s thesis

Telecardiology Data Collection in Low-Resource Environments

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Prague, May 2015

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DIPLOMA THESIS ASSIGNMENT

Student: **Bc. Dzian Rosion Versace**

Study programme: Open Informatics
Specialisation: Computer Engineering

Title of Diploma Thesis: **Telecardiology data collection in Low-Resource Environments**

Guidelines:

Develop a method allowing the remote assessment of cardiac function using store-and-forward and interactive Telemedicine paradigms in low-resource environments (lack of diagnostic devices, limited knowledge of patients regarding telemedicine, unreliable telecommunication, etc.).
The work can be broken down as follows:
1. Analyze requirements from the cultural, legislative, infrastructural and IT perspectives.
2. Study existing solutions and low cost pulse sensors in Telecardiology.
3. Develop a low cost method for patient data acquisition using physiological sensors (such as finger pulse sensor or other similar devices).
4. Implement an algorithm for data processing.
5. Develop a web-based front-end software solution for health/medical professionals and patients in a low-resource environment.
The main result is a web-based software system for cardiovascular data acquisition, storage and representation for the purpose of establishing a diagnosis.

Bibliography/Sources:

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Prague, March 6, 2015

Prohlášení

Prohlašuji, že jsem předloženou práci vypracoval samostatně a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

V Praze, dne 11.05.2015 ……………………………………….

Podpis

Acknowledgement

I would like to thank my supervisor Ing. Michel Kana, Ph.D. for dedicating a lot of his time and patience in order to help me write this thesis. His advice allowed me to improve the quality of the work. I would also like to thank my co-supervisor Ing. Michal Štěpanovský , whose practical advice helped me a lot.

Declaration

I declare that I worked out the presented thesis independently and I quoted all used sources of information in accord with Methodical instructions about ethical principles for writing academic thesis.

Abstrakt

Cílem této práce je vytvořit webovou platformu pro ukládání fyziologických dat použitím telemedicíny v prostředích s nízkými zdroji. Práce zahrnuje analýzu požadavků pacientů a lékařů v takových prostředích. První část práce se zabývá požadavky v oblasti telemedicíny včetně existujících Open Source řešení. Druhá část popisuje navrhnuté řešení a jeho implementaci.

Abstract

The aim of this thesis is to develop a web-based platform for patient physiological data acquisition and storage using store-and-forward and interactive telemedicine paradigms in low-resource environments. The work includes the analysis of difficulties encountered by patients and their health professionals in developing countries. The first part of the thesis deals with the analysis of requirements in telemedicine in low-resource environments and the study of the existing Open Source software. The second part describes the proposed solution and its design including the implementation of the system.

Contents

Chapter 1

Introduction

TELEMEDICINE is the use of telecommunication and information technologies to improve patient's clinical health status [1]. The aim is to improve a patient's health by allowing two-way interactive communication between the patient, and the physician or practitioner at the distant site.

The term "telemedicine" was first used in the 1970s, and literally means "healing at a distance" [2]. There is no definitive definition of telemedicine, but we can retain the one adopted by the World Health Organization: "*The delivery of health care services, where distance is a critical factor, by all health care professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for the continuing education of health care providers, all in the interests of advancing the health of individuals and their communities*" [4].

From the above definition, one can notice that emphasis is placed on the distance – meaning that telemedicine is mainly used to eliminate distance barriers and improve access to medical services that would often not be consistently available in distant rural communities. The given definition also highlights that telemedicine is an open and constantly evolving science, because it incorporates new advancements in technology and tends to respond and adapt to the changing health needs and contexts of societies and cultures. Actually telemedicine involves a growing variety of applications and services using two-way video, email, smart phones, wireless tools and other forms of telecommunication technologies. These technologies allow communication between a patient and a physician or other medical staff with both convenience and fidelity, as well as the transmission of medical, imaging and health information data from one site to another.

In addition to the above mentioned methods, telemedicine also uses client/server applications to deliver advanced diagnostic methods and telemedical devices to support in-home care.

To help understand the use of telemedicine, the American Telemedicine Association has dressed a list of examples of services provided and mechanisms used to provide those services in telemedicine. This includes remote patient monitoring, primary care and specialist referral services, and consumer medical health information. Telemedicine can also be used to provide medical education. [1]

Of course these are only examples of the use of telemedicine; many other services and uses may be involved in telemedicine. These examples, however, give us an idea of what telemedicine means in practice. We can summarize the use and importance of telemedicine by the following:

1. Its main goal is to improve patient's clinical health status
2. It is used to overcome distance barriers by providing services at distance and connecting patients to health staff located in different physical locations.
3. To fulfill its goals, telemedicine uses various types of telecommunication and information technologies.
4. Among the main benefits of telemedicine, we can mention cost efficiencies. It has been proven that telemedicine significantly reduces the cost of healthcare as it reduces travel times, and fewer or shorter hospital stays. It also increases efficiency through better management of chronic diseases [1]. Telemedicine can be beneficial to patients living in isolated communities and remote regions, who can receive care from doctors or specialists far away without the patient having to travel to visit them [6]. From this point of view, we can say that telemedicine can be vital and save lives in critical care and emergency situations.

Objectives and Goals of this Thesis

The aim of this thesis is to develop a method allowing the remote patient's data collection using store-and-forward telemedicine paradigms in low-resource environments (lack of diagnostic devices, limited knowledge of patients regarding telemedicine, unreliable telecommunication, etc.).

Our motivation is to analyze the major difficulties encountered by patients in regions with limited facilities in cardiology, e.g. developing countries and their regional health professionals and to design a data collection system using low-cost IT solutions.

The main result is a web-based software system for patient data acquisition, storage and retrieving for the purpose of establishing a diagnosis.

The work is broken down as follows:

- First we analyze requirements from the cultural, legislative, infrastructural and IT perspectives.
- In the second chapter we mention some existing solutions and approaches used to implement those solutions.
- The following chapters describe the design of our solution, including its implementation.
- The last part of the work covers testing.

Chapter 2

Requirements

2.1 Business Requirements in Telemedicine

Telemedicine is a relatively young and evolving field. Building a telemedicine application requires detailed domain analysis of users' needs. The requirements are various and differ from a country or a region to another. That is one of the reasons why objectives, technologies and even philosophies of each telemedicine system will usually differ from others.

However there are of course still common requirements that every telemedicine solution covers.

In order to have a clear understanding of specific user requirements in telemedicine in low resource environments, we have made a small survey back in 2013 [35]. The aim of the survey was to find out what are the main difficulties encountered by users while using telemedicine.

We received 14 answers from people living in Cameroun, Congo, Czech Republic, France and Switzerland. Unfortunately many people did not answer us, because they did not even know what telemedicine is. But the few answers we received from different countries gave us an idea of how some people consider telemedicine. Here is the summary:

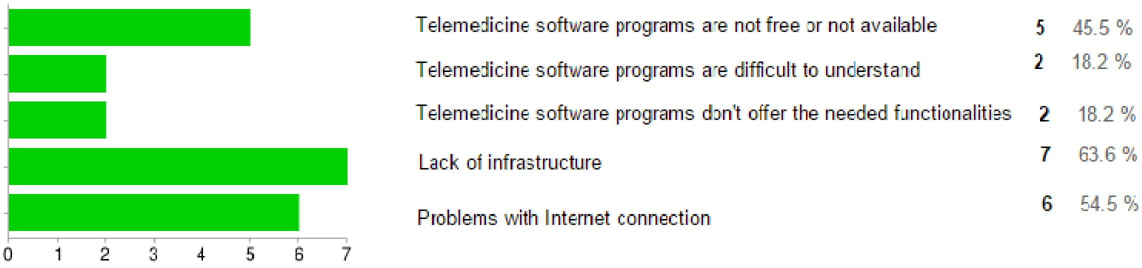


Figure 2.1

- More than 18% of participants thought that existing free telemedicine software programs are difficult to understand, so they would prefer a very easy-to-use system, and 18.2% shared the opinion that existing solutions do not offer the needed functionalities.
- Some mentioned the lack of infrastructure. In Congo, for example, certain medical centers do not even have a computer.
- Problems with Internet connection were also mentioned.
- Some questioned people recommended to first provide education in order for users to familiarize to telemedicine and its use.

The entire survey can be found in the appendix B.

We had also an opportunity to discuss personally with two doctors. Both insisted on the security of the system to protect patient's data. According to one of them, "clear rules regarding communication and confidentiality must be defined. Patients can be sceptic while using such systems. They may require some proof or confirmation that the system is really secure."

The second doctor mentioned that a telemedicine system should allow not only patient-to-physician remote communication, but also physician-to-physician remote communication. This can allow for example physicians in developing countries to consult their counterparts in other countries. This can lead to better results while making diagnosis. Again confidentiality rules must be clearly established.

In addition to this, we also made researches on the existing literature. Below are the results of our researches regarding requirements for a telemedicine solution in low-resource environments.

2.1.1 Requirements regarding distance barriers

As mentioned in the introduction, distance barrier is one of the basic problems faced by people living in rural and sometimes in completely isolated regions. Indeed, rural residents must travel longer distance than people who live in cities to get to hospitals. The challenge is made even more complicated by the largely absent public transportation systems [7]. Because ambulances and other emergency vehicles must travel so far, rural residents with emergencies receive medical attention more slowly than their urban counterparts. Most of the time, people who live in rural communities are more poor that those living in cities, so paying for the transport to get to the hospital or to a health center may complicate life to many people. For example a patient with chronic disease will have to spend a lot of money in order to receive appropriate heath care.

A telemedicine system should help overcome these issues by allowing access to specialists regardless of location. This can be done by using live video conferences or medical image or video sharing/communication portals. A telemedicine application should allow for reliable transmission of vital signs. This enables patient assessment by specialists in the specific pathology and immediate reception of appropriate treatment guidelines until the patient's arrival at hospital [8]. Allowing remote communication between patients and physicians or nurses can not only help in solving emergency and overcome the distance barrier, but it also helps saving money that would be spent for travelling purposes.

Many studies have been conducted to show telemedicine significantly reduces unnecessary transport of patients or medical staff. For example, one study in Peru, in the province of Alto Amazonas, shows an important reduction in emergency transport, which confirmed that the system was efficient and also demonstrated that the additional costs of maintaining the system were lower than the direct costs of the health system. [8]

2.1.2 Technology requirements

The success of telemedicine systems depends primarily on the various medical devices used to collect patient information and the telecommunication infrastructure used to share data with physicians or other medical staff.

Basically, we have the following categories [8]:

- **Terminal devices to capture patient biomedical signals.** This includes Electrocardiography (ECG or EKG) and sensor-based devices, such as glucose sensors, mobility and/or position sensors for the elderly or people with reduced mobility, temperature measurement devices etc.
- **Services, components and applications for healthcare management.** These may be software applications that enable service coordination (appointments, agenda setting), patient identification, patient file management (medical records system), messaging, data security systems, etc.
- **Telecommunication equipment and systems.** In telemedicine, the equipment used for both the patient and the specialist varies depending on concrete requirements. These include telephone terminals, personal computers, PDAs, video stations, computer peripheral equipment such as digital cameras, document scanners, high resolution screens, etc.
- **Communication network**. Communication network allows the transmission of information to a referral center.

In [9] Dr. Andrew Watson recommends strong platforms for managing people, locations and devices to address infrastructure issues. In developing countries, the choice of adequate technologies can be very difficult. In addition to the distance barrier, patients in rural areas must also deal with issues related to the lack of technologies. In many developing countries, people have still to deal with issues such as lack of electricity, poor or lack of Internet connection.

While designing a telemedicine system therefore, it is important to consider the availability of local infrastructures and select the adequate technologies adapted to those infrastructures to fit the local needs. A telemedicine system should propose a way to transmit data even in the context of poor or lack of Internet connection. For this purpose, alternatives should be used, such as mobile phones.

2.1.3 Requirements regarding Cultural Barriers

In the study *Barriers to Telemedicine: Survey of Current Users in Acute Care Units*, emergency and critical care robotic telemedicine users were asked to identify the factors that motivate and the barriers that impede the acceptance and maintenance of remote presence telemedicine. One of the barriers revealed by the survey was the cultural barrier that occurs because of lack of desire, or unwillingness, of some physicians to adapt clinical paradigms for telemedicine applications [13]. As revealed by our survey mentioned above, this is most probably due to the complexity of telemedicine applications, or to the fact that existing telemedicine applications do not always fit their needs. Building a simple, easy-to-use and flexible telemedicine application may motivate some physicians to start using it.

2.1.4 Ethic and Legal Issues

Despite of the increasing use of telemedicine, there are still a lot of discussions about the ethical and legal issues surrounding it. Using telemedicine implies many issues of concern regarding the legal and ethical aspects. Among them, we can mention the responsibilities and potential liabilities of the health physicians, the obligation to maintain the confidentiality and privacy of patient records, and the jurisdictional problems associated with cross-border consultations.

Issues regarding privacy and confidentiality in the medical realm are not necessarily different in telemedicine. As with conventional medicine, a telemedicine clinician has the same duty to safeguard a patient’s medical records and keep their treatments confidential.

Transmission and storage of electronic files, images, audios, videos, etc., needs to be done with the same caution and care as applicable to paper documents [10].

To cope with these issues, a telemedicine system must provide as much security as possible. Users must be sure while using the system that their data are securely protected against unauthorized users. To ensure maximum security, the system must use secure networks while transmitting data, stored data must be encrypted, appropriate authentication and authorization must be provided. .

2.1.5 Financial Problems

Another barrier to telemedicine is reimbursement. Medicare services lack reimbursement terms. This is due to the fact that there are no clear standards for payment or reimbursement for telemedicine in many countries [9].

In developing countries, there is significant limited competition for telecommunication services, which keeps the communication cost high [32].

In addition, the equipment designed for telemedicine, including hardware and software is also relatively expensive and therefore not accessible for many.

Due to these financial problems, the resources used by a telemedicine application must be low-cost, meaning that the selected resources to be used must be as cheap as possible. This includes software and hardware.

2.2 Functional and Non-functional Requirements

Based on the above analyze of business requirements, we define the following functional and non-functional requirements for our system:

2.2.1 Functional Requirements

- R1) The system must allow remote communication between patients and their health professional, in order to eliminate distance barriers between them.

- R2) The system should be flexible enough to allow managing different types of objects. It should be possible to manage not only people (users), but also other objects such as devices, documents etc.
- R3) The system must allow patient to send different kinds of data.
- R4) The solution should include a method for patient cardiac data acquisition
  The patient will have a possibility to measure, view and send heart rate signals to his doctor via the application.
- R5) Allowed users can log in into the system and view resources they are authorized to view. This means that the system must provide authentication and authorization. Different access rights will be defined for different users.
- R6) All patient data will be saved into a secured database.

2.2.2 Non-functional Requirements

- N1) The system should allow the use of mobile phones to transmit data. This will allow users with poor Internet connection to use the system with their mobiles phones.
- N2) The system should be easy to manipulate. As the system will be used by people who do not necessarily have good experience in the use of IT systems, it is required that the system will be user friendly and easy to manage.
- N3) The system should be adaptable to different business cases. Each organization has its own needs. The system should allow different organizations to adapt it to their needs.
- N4) The system must provide a high level of security. Because the system will work with patient’s data, it must provide different security methods to protect it, including encryption, secure transmission, authorization and authentication.
- N5) The implemented solution should be low-cost. The system will primarily be used in low-resource environments, e.g. developing countries; it should use the cheapest possible resources. That means that technologies and resources used to build the system must be adaptable in low-resource environments.

Chapter 3

Existing Solutions in Patient Management and Data Acquisition

With the advent of the Internet, many patients are eager to get information about their health instantly. As its name says, Electronic Health Record (EHR) refers to a systematic collection of electronic health information about an individual patient or population [15]. Sometimes the term Electronic Medical Record (EMR) is also used to refer to EHR. In many countries, the use of EHR is getting more and more popular. That is why many governments make considerable efforts to improve efficiency in medical services using EHR systems.

However, even though EHR systems have proven their efficiency, many healthcare organizations have yet to implement them. This is mainly due to financial reasons – medical software is expensive and many care providers such as doctors, hospitals, dentists, independent clinics and so on, have been under a lot of pressure to maintain or reduce run costs while at the same time continuing to provide the quality patient care and customer service expected of the medical care industry. [14]

In order to reduce the high costs of implementing IT systems in health care, many organizations opt for the use of Open Source Software (OSS). As the open source community continues to grow, the number of open source medical applications also grows with it. In this chapter, we discuss some of the most used OSS in telemedicine and their characteristics.

3.1 Existing Open Source Solutions

OpenEMR

OpenEMR is one of the most popular Free and Open Source electronic health records and medical practice management applications. It is ONC certified and supported by a strong community of volunteers and professionals.

Key Features:

- Multilanguage Support
- Electronic Billing
- Document management
- Integrated practice management

OpenEMR	
Type	Medical practice management software, Electronic Medical Records
Programming language	PHP
License	GNU General Public License
Website	www.open-emr.org

Table 1: Technical overview of OpenEMR

OpenVistA

OpenVistA is a fully-integrated clinical solution with all necessary functions to run hospitals and their clinics. It was designed to improve the care and patient safety for veterans and to be rapidly adoptable by clinicians.

OpenVistA provides clinical, administrative, financial, and infrastructural functions. It has been adopted for use by several other health institutions in US as well as hospitals in other countries, e.g. Egypt, Germany, and Mexico.

However, the technology used by Vista is not based on modern computer language or platform. [14]

Key features:

- Clinical documentation
- Health Information Management System (HIMS)
- Patient registration
- Scheduling
- Notification and reminders

OpenVistA	
Type	Electronic health record for all clinical field, based on veteran's hospital information system
Programming language	MUMPS, Delphy/Kylix
License	Public domain, GPL
Website	http://www.medsphere.com/open-vista

Table 2: Technical overview of OpenVistA

OpenMRS

OpenMRS is a collaborative open source electronic medical record system, entirely programmed in Java.

OpenMRS is also a community of people working to apply health information technologies to solve problems, primarily in resource-poor environments. It has been supported by the Google Summer of Code from 2007 [14].

Key features:

- Tools for data export and reporting
- Support for HIV/AIDS, Drug resistant TB, primary care and oncology
- Supports open standards for medical data exchange including HL7, LOINC and IXF
- Form-based tools, such as the Form Entry module and XForms module
- Bidirectional synchronization with systems such as MoTeCH and TRACnet

OpenMRS	
Type	Infection control system for developing countries
Programming language	Java
License	OpenMRS Public License
Website	http://openmrs.org/

Table 3: Technical overview of OpenMRS

PatientOS

PatientOS has been designed from the outset to be a HER. It supports not only human hospitals, but also veterinary care hospitals. It is a distributed web-based clinical system written in pure Java with toolset to customize.

Key Features:

- Scheduling,
- Orders,
- Meds,
- Pharmacy,
- Clinical documentation

PatientOS	
Type	Free healthcare information management system designed for hospitals and healthcare practitioners.
Programming language	Java
License	GNU GPL
Website	http://www.patientos.org/

Table 4: Technical overview of PatientOS

GNUmed

The GNUmed project builds free, liberated open source Electronic Medical Record software in multiple languages to assist and improve longitudinal care (specifically in ambulatory settings, i.e. multi-professional practices and clinics).

It is made available at no charge and is capable of running on GNU/Linux, Windows and Mac OS X. It is developed by a handful of medical doctors and programmers from all over the world.

Key Features:

- Appointment handling,
- Document archive,
- Medication Handling,

- Vaccination Handling

GNUmed	
Type	EMR, specifically in ambulatory settings
Programming language	Python
License	GPL
Website	http://www.gnumed.org/

Table 5: Technical overview of GNUmed

FreeMED

FreeMED is an open source electronic medical record system based on LAMP – Linux, Apache, MySQL and PHP. The project was initiated by Jeffrey Buchbinder in the United States in 1999. Since then, it has become an international growing up project, with thousands of downloads and several translations.

FreeMED is currently hosted by a non-profit corporation, called FreeMED Software Foundation. The corporation also provides commercial support for FreeMED.

FreeMED	
Type	Electronic medical records system for general practitioner clinics
Programming language	PHP
License	GPL
Website	http://freemedsoftware.org/

Table 6: Technical overview of FreeMED

SmartCare

SmartCare is an internationally distributed electronic medical records tool that was developed by the government of Zambia in collaboration with the Centers for Disease Control and Prevention (CDC) and many other implementing partners.

The application is currently widely used in Zambia, Ethiopia and South Africa. It was designed in order to support clinics that need to interface internationally, but also have co-existing paper based systems. It is also built around the assumption that many of the clinics may not have ubiquitous access to telecom systems or even reliable electrical power [16].

Key Features:

- Distributed database system
- Smart Card used to store health information
- Touchscreen allowing the clinician to view and record patient data

SmartCare	
Type	Electronic health record system (EHR)
Programming language	

License	
Website	http://smartcare.org.zm/

Table 7: Technical overview of SmartCare

CottageMed

Cottage Med is an electronic medical record software based on FileMaker. It uses templates that interact with the FileMaker database management program.

The project was officially created in 1999 by the physician Stefan Topolski. It is one of the first publicly distributed free EMR systems to be both open source and cross-platform for PC, Mac & Linux in the world.

Key Features:

- CottageMed became Basic accounting functions
- Full and flexible access to all data fields
- Powerful search functions on any and all fields
- Report generation

CottageMed	
Type	Electronic health record system (EHR)
Programming language	
License	GPL v2
Website	www.cottagemed.org

Table 8: Technical overview of SmartCare

ClearHealth

ClearHealth is another web-based open source practice management and electronic medical records system. Available under the GNU General Public License, it is been used by a number of large institutions, including the Primary Care Coalition network out of Maryland, USA [16].

ClearHealth is developed in the PHP programming language and it is able to be run on most server configurations, in Windows, Linux or Mac OS and it uses Web Servers such as Apache and MySQL database.

Key Features:

- Scheduling
- Patient registration
- Electronic medical records
- Electronic and paper billing
- SQL reporting
- Support for manipulation of with data in HL7 and Continuity of Care Record (CCR) formats

ClearHealth	
Type	Practice management and electronic medical records system
Programming language	PHP
License	GPL
Website	clear-health.com

Table 9: Technical overview of ClearHealth

OpenDental

The last electronic medical records application we would like to mention is OpenDental. It has the specification of being focused on dental care providers.

Previously known as Free Dental, OpenDental is owned and sponsored by Open Dental Software, Inc., which is incorporated in the State of Oregon in the United States of America. It is written in the C# programming language compatible with Microsoft .NET Framework.

Key Features:

- Online patient forms
- 3D movable teeth
- Text messaging
- Mobile Web application
- Kiosk
- Signature pads
- Multipage scanning

OpenDental	
Stable release	
Programming language	C#
License	GPL
Website	www.opendental.com

Table 10: Technical overview of OpenDental

3.2 Discussion about Existing Open Source Solutions

In the previous section we presented some existing Open Source solutions in telemedicine. It is obvious, that Open Source Systems have a great potential in offering low-cost and relatively quality electronic health records systems. This is a great alternative to proprietary solutions for developing countries with limited financial resources.

Advantages of Open Source

Among the benefits of Open Source, we can mention the following [17]:

- ***Open Collaboration***

One of the most significant advantages of the use of Open Source is the fact that it involves an open collaboration and transparency. Many people come with new ideas and share them with others. Most of the time, they do not hesitate to criticize and improve other's work. Instead of being hidden, problems are exposed early, open to see and fix.

Being open, the code is free to be evaluated by a large community, which accelerates the innovation, allows testing to be done by a broad audience. Moreover, there are no timetables or deadlines, and release does not occur until the product is refined.

- ***Modularity***

Another great advantage of open source applications is the fact of being most of time modular. Modularity allows software to be easily extended and to collaborate with other systems.

- ***Interoperability and standards***

The open source programming model has being shown to facilitate development of interoperability and standards [17]. In open source model, developers usually use existing project as a reference and build upon it. This makes standardization quickly achieved.

Drawbacks of Open Source

From the above, we can clearly say that Open Source has many attractions. However, it also has some barriers that must be considered. Let us mention some of them:

- ***Lack of Non-Programmer Configurability***

Open source software depends mainly on volunteers and is usually proposed 'as is'. This may be a problem for organizations that require EMR to be configurable to some degree [17]. This requirement is legitimate, as clinics and hospitals or other health organizations have different workflow and unique local environments and needs. This configuration has to be often done by a non-technologist clinician who understands this complex workflow.

Many open source applications in EMR that are mentioned in this chapter are ultimately configurable, but most of them are complex and require a higher level of technical expertise.

If we consider for example OpenEMR, for a non-programmer user who would like to start using it, it may be a big challenge to even get started. The application includes many modules that make it too complex for a beginner. Some of the modules may not be needed and it may be very difficult to get rid of them and keep just the needed ones.

- ***Perceived Lack of Security***

As already mentioned, clinical information systems require a high level of security in order to maintain patient privacy.

Some people are skeptical about security of open source software due to the openness of its code [14]. Of course this perception may be wrong. Open source software can theoretically be made more secure than proprietary software because it can receive input from many developers, which allows the immediate identification of security risks.

- ***Lack of Knowledge and Trust***

Many health organizations lack knowledge about open source possibilities [17]. Some are afraid of using an application that is free. For them “free” means without values and will certainly not achieve their needs. They perceive in it a lack of accountability regarding quality, security and liability.

Hospitals and providers also have to solve the question of support while opting for open source solutions. If the system gets down, who will provide support? Complex open source software requires qualified programmers familiar with it to provide continuous support.

- ***Difficulty Interfacing with Proprietary Products***

Another barrier to the use of open source is the difficulty to include and connect it with proprietary resources due to the GPL license. This can occur for example with labs, e-prescription networks, and decision support databases. [17]

This difficulty can be overcome if open source software uses a license that allows third parties to keep code proprietary.

The reason why we did not choose one of them to build our system is that we did not find one that fulfils *all* the requirements defined in section 2.2. According to the report mentioned in [33], PatientOS , OpenVistA are complex and difficult to install and configure (do not meet requirement N2). OpenEMR is not customizable and OpenMRS does not allow practitioner-customization, both do not match requirement N3. OpenDental is specific, as it focused on dental care providers. For this reason, it does not fit N3 requirement. After personally trying the other OSS, we can also affirm that they do not fit all our requirements, especially N3 requirement defined in the above chapter. Proprietary solutions were not considered as they mostly do not meet the low-costs requirements.

Chapter 4

Solution Design

This chapter introduces the design of the solution we propose in this work.

Low-resource environments constraint for our solution requires the system to be easy to use, flexible and configurable. Such a system will not require unnecessary resources, because organizations will configure and adapt it to their needs, according to the available resources. For example knowing that their Internet connection is not good, they may wish to share only data that can be sent through the available bandwidth.

For the system to be flexible and configurable, we propose to build a generic model. The Proposed Concept was taken from [29] and is described as follows. The idea behind the generic model is to propose a ***meta model***, and allow each organization that will use the system to build its ***own specific model*** using our meta model. Meaning that, instead of hard-coding a specific concept, we let the organization define its own.

While an organization may wish to manage only patients, physicians, nurses and devices, another one would maybe want to manage patient visits as well. Another will not have nurses in the system at all, but only patients and physicians.

As we can see in the scenarios above, each organization has its own needs. Our ambition, therefore, is to build a system that will be flexible enough to respond to all these needs. The key for the success of such a system is a clever generic (or meta) data model: instead of defining model specific classes such as Patient, Physician, Nurse, Device, etc., we simply define a generic class called ***Resource Type***. This meta class will then encapsulate specific classes such as Patient or Physician. When installing the system, the organization will not only be able to define its specific Resource Types, but also set relationships between them.

A system having such characteristics will match requirements R2, R3, N2 and N3, defined in section 2.2.

4.1 Definitions

- ***Resource Type***

  A *Resource Type* is a meta class used internally by the system to encapsulate specific classes. Because the model is generic, we do not directly define specific resources like Patient or Physician, because we do not now in advance if organizations will incorporate them into their model or not. But we assume that organizations may wish to have such resources and therefore we prepare a “place” for them and give them a generic name: Resource Type. Thus, a Resource Type can be whatever: Patient, Physician, Device, Diagnosis, Document etc.

- ***Resource Meta Type***

Resource Types are grouped in different categories called *Resource Meta Type*. For example, Resource Types Patient, Physician and Nurse can be categorized as **Human**; Hospital, Device and Room are **Material;** and finally Diagnosis and Medical Record are **Abstract**. *Human, Material* and *Abstract* are examples of *Resource Meta Types*.

- ***Resource Type Attribute***

Each Resource Type has some attributes. For example if we create a Resource Type Patient, then we can also create its attributes like Name, Age, Personal Number, and so on. In this model, we refer to each of them as *Resource Type Attribute*.

- ***Resource Type Attribute Type***

Each Resource Type Attribute has some characteristics: it can be mandatory or not, it can be binary, printable, etc. A *Resource Type Attribute Type* represents such characteristics.

- ***Resource Type Binding***

Two Resource Types may have a relationship between them (i.e. a Patient can be related to a Doctor and vice versa; a Patient might have a Diagnosis). This relationship is called *Resource Type Binding*. In this relationship, one ResourceType is set as the parent of the other.

- ***Resource***

A *Resource* is a specific record, or an instance of a Resource Type. If we have a Resource of type Patient, then we refer to a given patient (i.e. Jean-Paul) as a Resource.

- ***Resource Attribute***

A *Resource Attribute* is an instance of a Resource Type Attribute.

- ***Resource Binding***

A *Resource Binding* is a specific record of a Resource Type Binding. Assume we have created two Resource Types Patient and Diagnosis and defined a Binding between them. Then for a given patient (i.e. Jean-Paul), we call its diagnosis (i.e. diagnosis number 1234) Resource Binding. In other words, the diagnosis number 1234 is a binding of the Resource Jean-Paul (of type Patient).

- ***Organization***

An *Organization* is an entity, such as an institution. It can be a hospital, clinic, health care center, etc.
In this model, it is possible to define more Organizations in the system. Organizations are grouped in a hierarchic structure – meaning that an Organization can have one or

more children and one parent. One and only one Organization is set as the root. The root Organization does not have any parent.
Resource Types are contained in different Organizations. Each Organization, therefore, has a list of Resource Types contained within it.

- ***User***

A system *User* is an actor who interacts with the system. We distinguish two types of users:

- Ordinary User: a normal user with limited access to the system.
- Admin: a more privileged user, who can perform more actions than the ordinary user (see the next part).

The admin can grant access rights to each user, allowing performing or not some specific actions in the system.

- ***User Group***

Users are categorized into groups called *User Group*. Each user belongs to at least one group. Access rights are also defined for each group.

4.2 Use Cases

This section describes the system Use Cases, i.e. the list of actions defining interactions between an actor (user or admin) and the system.

The first diagram (figure 4.1) shows all basic actions that can be performed by the system user. An ordinary user can login into the system, view its profile, change its password and update its personal data (if he is allowed to do so).

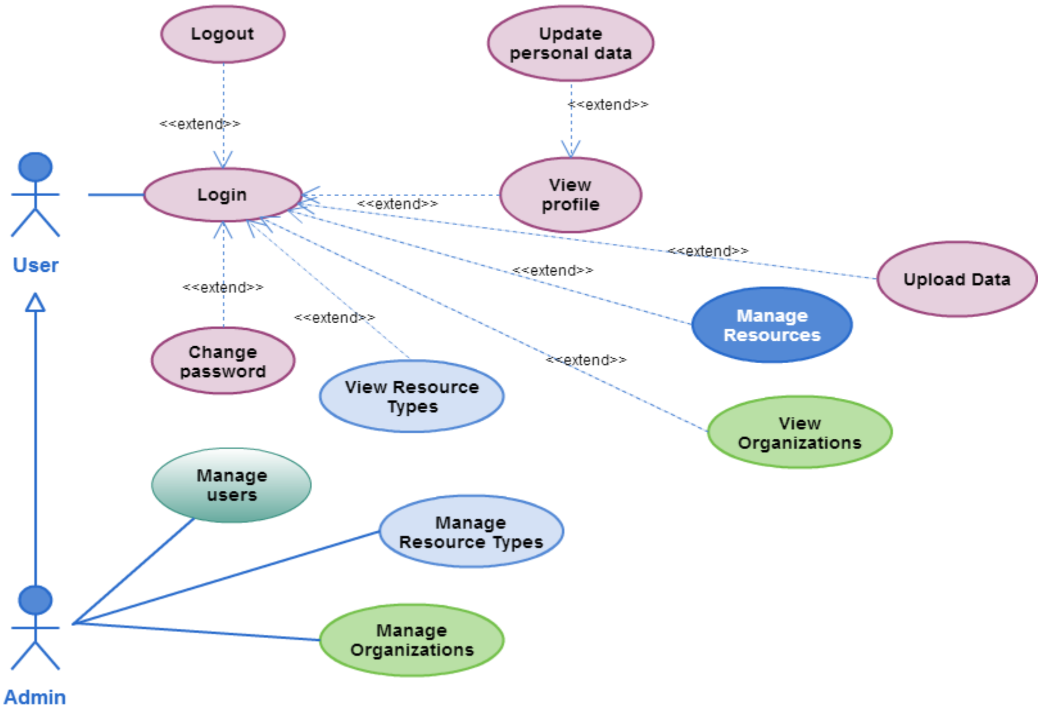


Figure 4.1: Use Cases – Basic actions performed by system user

An ordinary user can eventually view Organizations and Resource Types and possibly manage some Resources on which he has access rights.

The admin user inherits all actions of the ordinary user, meaning that he is able to perform all use cases an ordinary user can perform. In addition to this, admin can also manage users, Organizations, and Resource Types.

The diagram in figure 4.2 illustrates use cases for managing users. As shown in the diagram, the admin can not only manage users (add, edit and remove), but he can also manage groups and access rights. Thus, he can grant access rights to specific users or to a group or users.

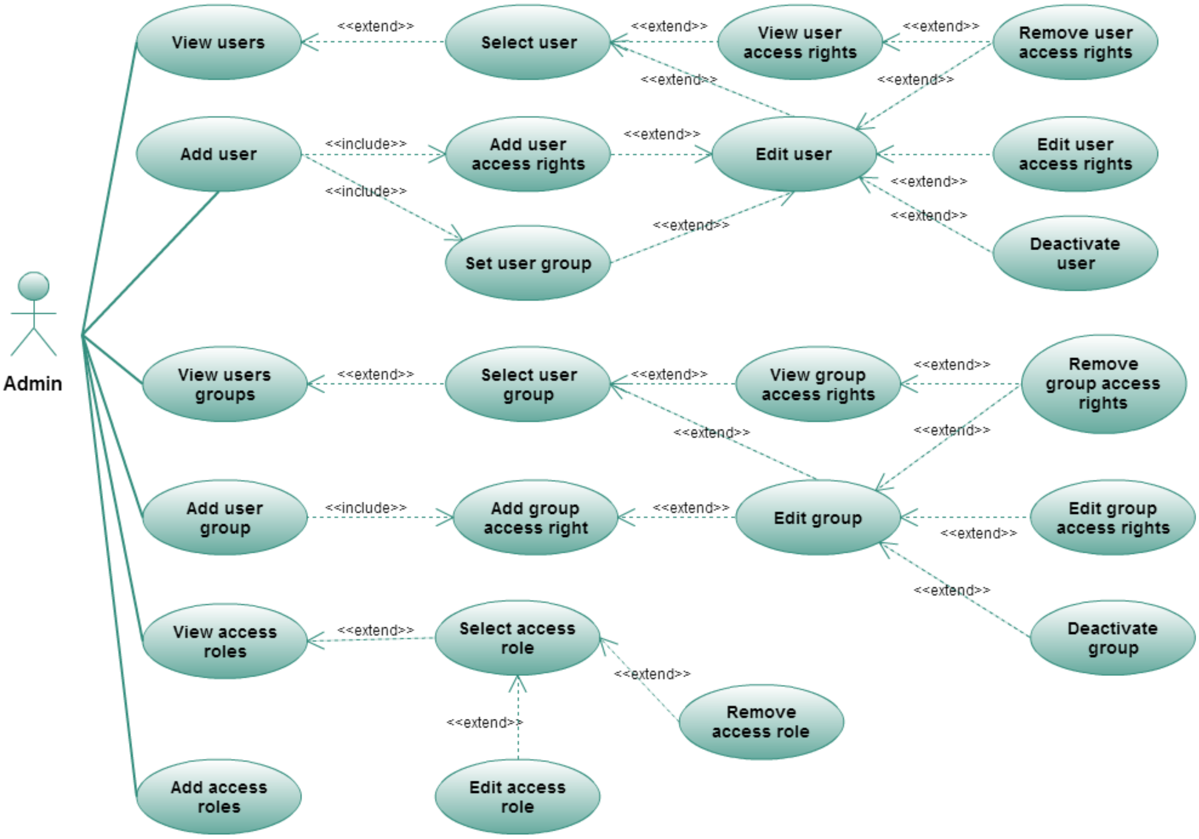


Figure 4.2: Use Cases – Users management

The admin can also manage Organizations, as shown in figure 4.3. This includes adding a new Organization, editing or removing existing ones.

In figure 4.4 we can see use cases for managing Resource Types and their attributes and bindings. When installing the system, the admin can create Resource Types and their attributes. He can also define relationships between the created Resource Types by adding bindings.

Later he can define other Resource Types, edit or remove existing ones. It is also possible to add new bindings and new attributes and to edit or remove the existing bindings and attributes.

After the meta data are created (i.e. Resource Types, Resource Type Bindings), data records can be added. Figure 4.5 shows use cases for manipulating Resources. This includes adding new records (resources), editing and removing existing ones. It is also possible to view Resource Bindings, add new Bindings, edit or remove the existing ones.

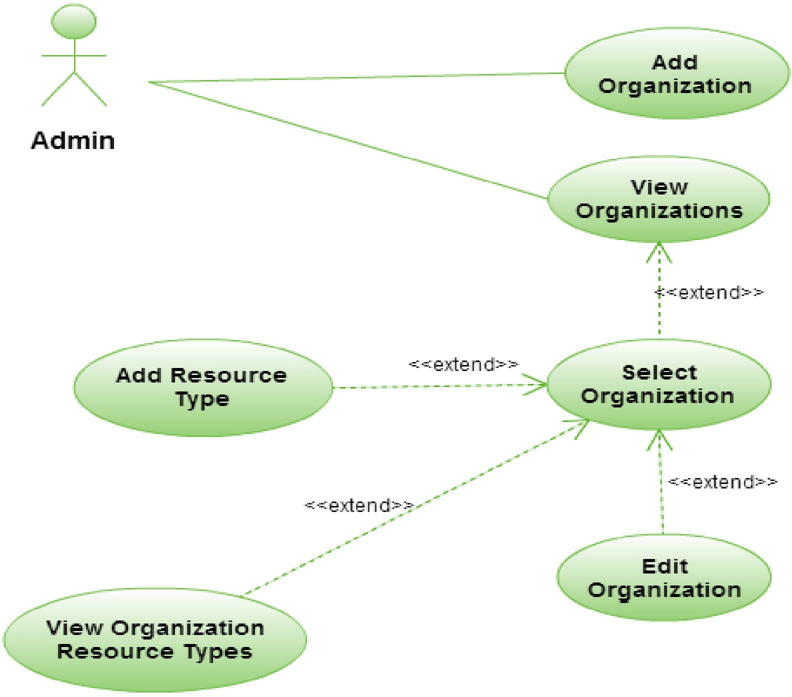


Figure 4.3: Use Cases – Organizations management

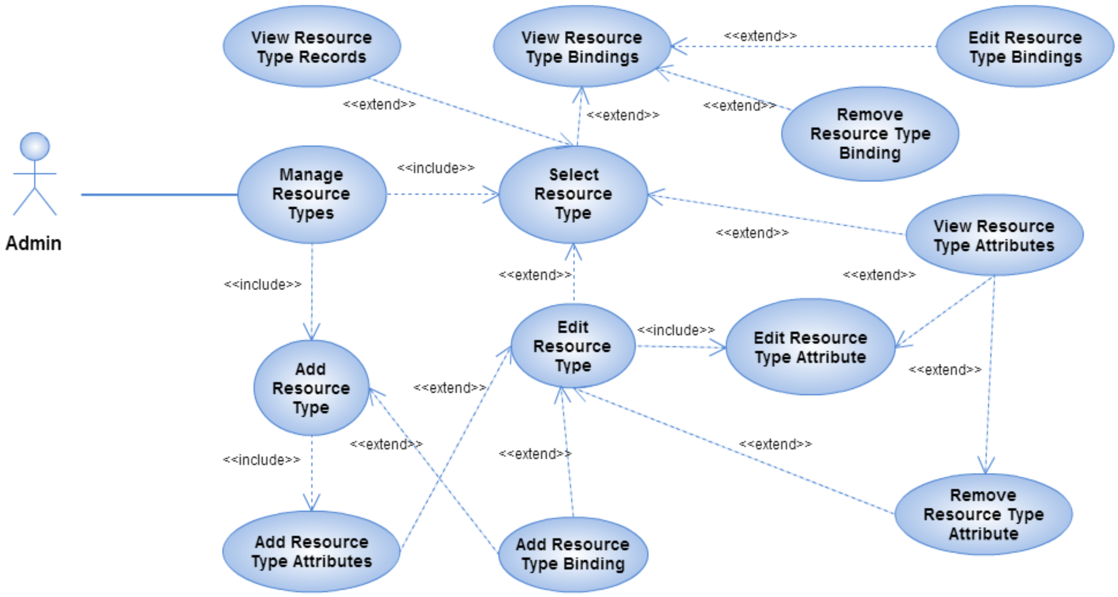

View Resource Type Records
View Resource Type Bindings
<<extend>>
Edit Resource Type Bindings
<<extend>>
<<extend>>
<<extend>>
Remove Resource Type Binding
Admin
Manage Resource Types
<<include>>
Select Resource Type
<<extend>>
View Resource Type Attributes
<<include>>
<<extend>>
<<extend>>
Edit Resource Type
<<include>>
Edit Resource Type Attribute
Add Resource Type
<<extend>>
<<extend>>
<<extend>>
<<include>>
<<extend>>
<<extend>>
Remove Resource Type Attribute
Add Resource Type Attributes
Add Resource Type Binding

Figure 4.4: Use Cases – Resource Types management

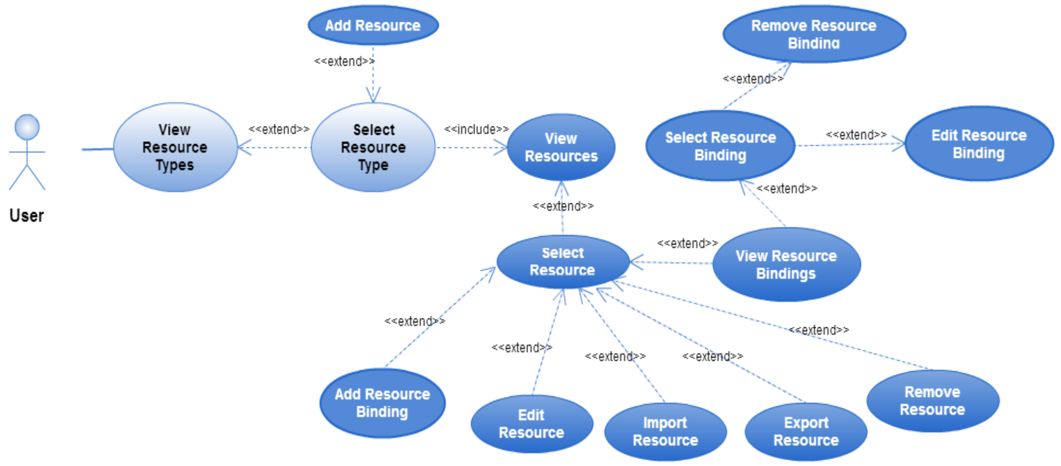


Figure 4.5: Use Cases – Resources Management

4.3 System Architecture

One of the main requirements of the system is to allow patients to send data to their physicians. In order to realize this function, we use a system architecture based on REST – Representational State Transfer. REST is a software architecture style for designing networked applications (web services). Rather than using complex mechanisms such as CORBA, RPC or SOAP to connect between machines, simple HTTP (Hypertext Transfer Protocol) is used to make calls between machines [18].

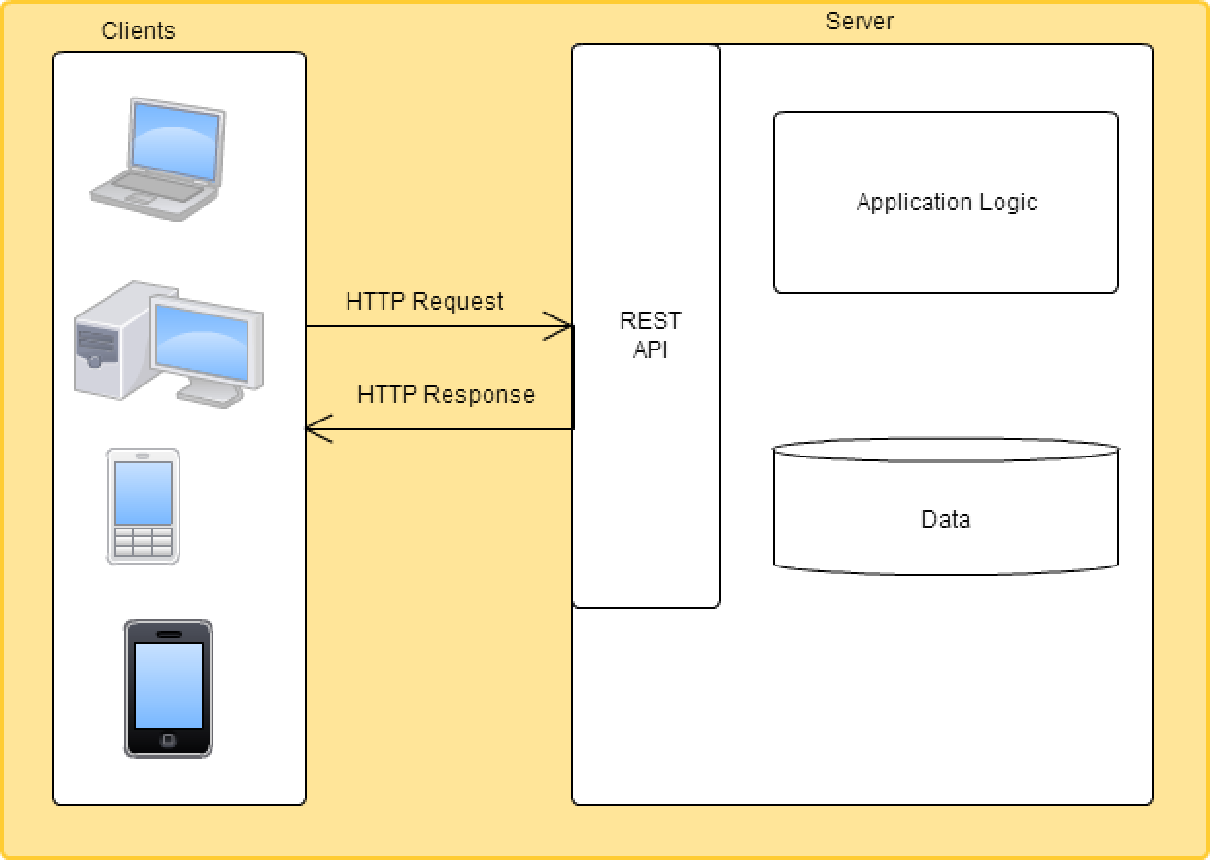


Figure 4.6: Global overview of the system

This architecture uses the client-server model for communication. This means that tasks or workloads are portioned between the provider of a resource and service, called server, and service requesters, called clients.

Rest architecture is good a choice for us, as it fits the low-resources requirement, for the following reasons:

- The client and the server are completely separated – each of them may be replaced and developed independently [20, 21]. The only thing that connects them is the interface existing between them. This leads to separation of concerns (SoC). Clients are not concerned with data storage. This allows the client code to be more portable and simpler [21]. Meaning that the client can be easily installed in patient's post without the need of installing a database server. The client can be simply a web form installed in patient's PC or mobile phone, for example. [21]
- The protocol is stateless: each request is an independent transaction that is unrelated to any previous request so that the communication consists of independent pairs of request and response. That means that no client context is stored on the server between requests. Operations are self-contained, and each request carries with it all the information (state) that the server needs in order to complete it. Thus, the server is not required to retain session information or status about each client [20]. The server code is therefore simpler and more scalable.
- The service is platform-independent.
- The service is language-independent (clients can be written in other languages than the server).
- The architecture is standards-based, as we use HTTP for communication.

This architecture fulfills also our security requirement, because it allows the use of security standards like HTTPs and it can easily be used in the presence of a firewall [18].

4.3.1 The Server

The server is the main application, responsible for managing clients' requests and serving them. The server application is also used for managing Resource Types, Resources, Organizations and users. It is the central part of the system, administered by an organization (hospital, clinic or another health organization).

4.3.2 Clients

The client side of the system will be mainly used, but not only, by patients to send their data to the server. There may be many clients, each being specialized for a given Resource Type. For example, if the Resource Type is Patient, then a client can simply generate a form for filling Patient attributes such as Name, Age, ID number etc. But if the Resource Type is heart rate data measured by a sensor and saved into a file, then a client may be specialized for reading such file and generating attribute-value sets that will be sent to the server. Another client can send patient's medical data.

4.3.3 Description of the HTTP API

As already mentioned, both client and server use HTTP (HTTPs) for communication. Because clients will be sending data to the server, the HTTP POST and PUT methods are used, as their allow posting data to the server. The GET method can also be used to send data to the server, but is less secure compared to POST because data sent is part of the URL [20]. Thus, we choose the POST method to fit the security requirement. We use POST for inserting new data, and PUT in case we want to update existing data. This is according the HTTP recommendations [20].

This section describes the API or application programming interface used for the communication between the clients and the server. Concretely, it deals with the design of the model of resources to be shared between clients and server. This includes the identification of the resources, the format used to represent those resources and the attribution of URL for getting them.

Data Representation

We use the format called JSON to represent data. JSON stands for JavaScript Object Notation and it is an open standard format that uses human-readable text to transmit data objects consisting of attribute–value pairs. It is completely language-independent and easy for machines to parse and generate. [19]

JSON is built on two structures:

- A collection of name/value pairs
- An ordered list of values

Note that this is not the internal data representation in server's nor in client's side. This is used only for the communication. The server has its own data structure (described in chapter 5), which is unknown to the client. Each client may also have its own internal data representation, and the server will not "care" of what it can be.

Making a HTTP Request

The client application addresses the server using standard HTTP request. Each request sent by a client contains the authentication information (login and username) in the header and the body is made of:

- **Resource id**: id of the resource for which data are being sent. If data to be sent is for example patient's documents, pictures or heart rate, the resource id will be the patient id.
- **Data**: data to be sent to the server. The admin has to specify which users are allowed to upload data for chosen Resource Types.

There are two kinds of data that can be sent:

  - ***Binary data (file)****:* this is used when data to be sent are saved in a file. It is possible to send more files at once. Each file to be sent has the following attributes:

- ***AttributeCode***: this refers to a specific Attribute of a Resource Type. For example the Resource Type Patient may have an attribute called Documents. So, when sending a patient’s document, the client must specify “Documents” as the value of the attributeCode field.
- ***Filename***: the name of the file that is being sent.
- ***Size***: the size of the file.
- ***Content***: the file content. This content must be encoded into a text using Base64 method.

Here is an example of what it looks like:

```
{"files":[
 {"file":[
  {"attributeCode":"DOC",
     "filename":"a-conrete-file-name",
     "size":"file-size",
     "content":"file-content-base64-encoded"}]},
{"file":[
  {"attributeCode":"PICTURE",
     "filename":"another-file-name",
     "size":"another-file-size",
     "content":"another-file-content-base64-encoded"}]}
]}
```

- **Text data**: the set of attribute–value pairs, where attributes are the Resource Type Attributes of a given Resource Type. Example:

```
{"data":[
  {"firstName":"John", "lastName":"Doe"},
  {"firstName":"Annabel", "lastName":"Gates"},
  {"firstName":"Peter", "lastName":"Steven"}
]}
```

It is also possible to combine both binary and text data within one request. The format is shown in the following example:

```
{"data":[

      {"file":[
        {"attributeCode":"DOC",
           "filename":"a-conrete-file-name",
           "size":"file-size",

     "content":"file-content-base64-encode"}]},
  {"firstName":"John", "lastName":"Doe"},
  {"firstName":"Annabel", "lastName":"Gates"},
  {"firstName":"Peter", "lastName":"Steven"}
]]}
```

As one can notice, the *file* field is inside the *data* field, and not the contrary. This must be respected; otherwise the request will be invalid.

A complete valid request body may look like this:

```
{

 {"resourceID":"12345"}

"data":[

      {"file":[
        {"attributeCode":"heartrate",
            "filename":"my-heart-rate.txt",
            "size":"58096",

     "content":"23s84weeej4smndjd09emsjdaszzzzxxxxpoe9982njd-
0sdsdsdksdj8uuennenn7ee7766636636hgbnssnndddndnddgbddny09983ndjdndndndn
dnkjshdkjsdhsjkdhjkdhjksdhjksdhkjshdkjn[psdnd’]]ddddsdsdsdsdsd9e8snsd
jsdjsddddddddddddddddddddddddddjjnndedjdjdjd"}]},
  {"firstName":"John", "lastName":"Doe"},
  {"firstName":"Annabel", "lastName":"Gates"},
  {"firstName":"Peter", "lastName":"Steven"}


]]}
```

Making the HTTP Response

The server responds to each client request using standard HTTP response. The response contains standard status code and possibly data required by the client.

The following table contains all status codes that can be sent by the server. Note that these are some of the standard HTTP status codes [20].

HTTP response	Description
200 OK	Successful request.
201 Created	Request to create a new resource is successful.
204 No Content	The server fulfilled the request, but does not need to return a response body.

HTTP response	Description
400 Bad Request	The request could not be processed because it contains missing or invalid information. For example the bad JSON format; file sent is too big.
401 Unauthorized	The credentials provided with this request are missing or invalid.
403 Forbidden	The server recognized the given credentials, but the user does not have proper access rights to perform this request.
404 Not Found	URI provided in a request does not exist.
405 Method Not Allowed	The HTTP method specified in the request is not supported for this URI.
500 Internal Server Error	The server encountered an unexpected problem which prevented it from fulfilling the request.
501 Not Implemented	The server does not currently support the functionality required to fulfill the request.

Table 11: status codes sent by the server

The Resource Identification

Each resource is uniquely identified by a so-called Request-URI – *Uniform Resource Identifier* (URI). The URI notation is usually in the format containing a *relative path*, related to some base address. The base address depends on the final placement (deployment) of the application. It will be the (root or other specific) address of the server on which the application will be deployed. That is why we do not consider it here.

All requests will use the following format:/service/action/resource_type/*

- **Service**: this is the name of the service provided by server (i.e. data upload). For illustration purposes we implemented one service called ***restDataTransmitter***.
- **Action**: this tells the server which action or operation to perform in order to serve the client's request. 3 actions (operations) are currently supported:
    - add_resource: used for creating a new Resource
    - add_binding: used to create a Resource Binding
    - add_binary: used to send a file

  If the specified Action is not supported by the server, the server returns the status code 501 in its response (Note Implemented – see table 11).

- **Resource_type**: this is the name of the Resource Type related to the client's request. It can be patient, diagnosis, heart_rate. It must match the exact name of an existing Resource Type on the server, otherwise, the server will return the 404 status code (Not Found – see table 11). To determine the exact name of Resource Type, we use a naming convention: Resource Type names used in the request are singular and CamelCased. Examples of the correct Resource Type naming in requests are:
    - Patient,
    - PatientDiagnosis and
    - PatientHeartRate.
- The asterisk "*" means that the request may have some parameters. The parameters are specified in the following format:
  parameter1/value1/
  In the case of more parameters, the format will be:
  parameter1/value1/parameter2/value2/parameter3/value3

The following table gives examples of valid Request-URI:

Request-URI	Description
/restDataTransmitter/add_binding	Add a new Resource of type.
/restDataTransmitter/add_binary	Used to send some binary data.
/restDataTransmitter/add_resource	Used for example by a doctor to remotely add a new patient to the system.

Table 12: examples of requests-URI

Chapter 5

Implementation of the Server

This chapter describes the implementation of the proposed solution in details, focusing on the server side of the system. First we introduce technologies used for the implementation of the server application, and then we describe the application structure and the data model used in the server part of the application. Some implementation details are also discussed in this chapter.

5.1 Used Technologies

The server application is completely programmed in the ***PHP*** script language. PHP is a server-side scripting language primarily designed for web development (but can be used as general-purpose programming language as well).

For the database we use the relational database management system called ***MySQL***, which is a popular choice of database for use in web applications.

As the HTTP Server, we use ***Apache,*** the world's most widely used web server software. This combination of technologies (Apache, MySQL and PHP) is sometimes called LAMP or WAMP, depending on the operating system on which there are installed. LAMP stands for ***L***inux ***A***pache ***M***ySQL and ***P***HP (Perl, Python). The “W” in WAMP means Windows. [21]

These technologies are selected to match our requirements (low-cost and low-resource). In [20] and [30] a list of server-side programming languages is dressed. The most used ones are PHP (82%), ASP.NET and Java. But ASP.NET is platform-dependent and requires Windows hosting, which is most of the time more expensive then Linux hosting [30]. Furthermore, Scripting languages like PHP could be easier to learn for beginners then Java. By choosing PHP, we allow potential feature developers to be able to continue the development of the system. The PHP programming language is usually used with Apache and MySQL. These two technologies do not present any serious drawbacks for any of our requirements, mentioned in chapter 2.

5.1.1 The Used Framework

In order to facilitate the development of the application, we use a web application framework (WAF) called CakePHP – an open source framework written in PHP. CakePHP uses well-known software engineering concepts and software design patterns, such as Convention over configuration, Model-View-Controller, Active Record, Association Data Mapping, and Front Controller. [20, 21]

Among all the features that come with CakePHP, the following are very significant: [21]:

- MVC architecture

CakePHP follows the MVC (Model–view–controller) software design pattern, which allows strict separation of the application into three main parts called Model, View and Controller (more about it in the next section). This concept turns the application into a maintainable, modular package and allows new features to be added without breaking the old ones. Developers and designers can work simultaneously, including the ability to rapidly prototype.

- Security

CakePHP comes with built-in tools for input validation, CSRF protection, Form tampering protection, SQL injection prevention, and XSS prevention, helping the programmer keep the application safe and secure. The security component of Cake also allows the use of SSL (Secure Sockets Layer).

- Localization

The internationalization and localization features provided by Cake make it easy for the application to be quickly translated in multiple languages.

- Documentation

CakePHP is one of the most documented frameworks. All features, including the API are well documented, with examples allowing new developers to quickly get started with the framework.

- Many useful components

CakePHP provides many other components such as

  - Authentication: for identifying, authenticating and authorizing users,
  - Session: provides a way to persist client data between page requests,
  - The Request Handler: to manage HTTP and HTTPs requests.

5.2 Structure of the Application

Because the server application is developed using the CakePHP framework, it has the same structure like all CakePHP-based applications. In this section we describe this architecture, based on the information provided CakePHP documentation in [21].

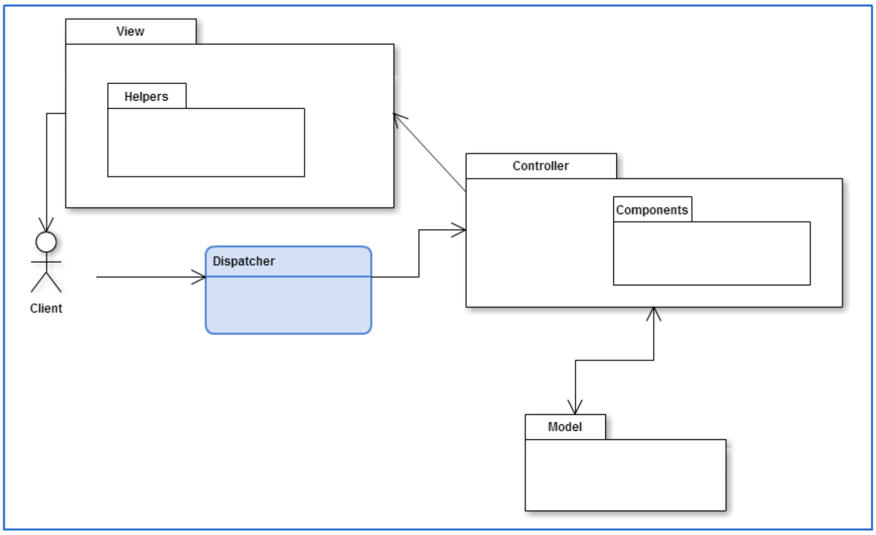


Figure 5.1: The Server Architecture

Figure 5.1 shows the architecture of the server application. The application is divided into 3 main layers: The Model, View and Controller layers. In terms of Object-oriented programming, theses layers are nothing but packages containing classes.

5.2.1 The Model Layer

The Model Layer is the central component of MVC that implements the business logic and rules of the application. It captures the behavior of the application in terms of its problem domain, and it is independent of the user interface.

The Model directly manages data. That means that it is responsible for retrieving data and converting it into meaningful concepts for the application. This includes processing, validating, associating or other tasks related to handling data.

5.2.2 The View Layer

The View Layer is responsible for rendering a presentation of modeled data. It uses the information it has available to generate an output representation to the user. The View is completely separated from the Model Layer and it is not limited to HTML or text representation of the data. It can be used to deliver data in different formats, such as XML, PDF videos, music etc.

5.2.3 The Controller Layer

The aim of the Controller layer is to handle user's requests. It collaborates with the Model and the View layers to render a response to the client (user).

The Controller layer is nicely described in [21]: "*A controller can be seen as a manager that ensures that all resources needed for completing a task are delegated to the correct workers. It waits for petitions from clients, checks their validity according to authentication or authorization rules, delegates data fetching or processing to the model, selects the type of presentational data that the clients are accepting, and finally delegates the rendering process to the View layer*."

Controller classes contain public methods called actions.

5.2.4 Components and Helpers

As one can notice in figure 5.1, besides the 3 main layers we have just described, there are also two sub layers that are part of the application structure: Components and Helpers.

Components

Components are packages of logic that are shared between controllers. Instead of having the same functionality repeated in two or more controllers, we put it in special packages called Components. Components keep controller code clean and allow the reuse of the same code between controllers or even projects.

Helpers

Helpers are more like Components – they are used to avoid code repetition. The difference with the Components is that Helpers are used in the View Layer (see figure 5.1). They contain presentational logic that is shared between many views.

5.2.5 Request Cycle

Figure 5.1 also describes cycle of user (client) requests and the way they are handled by the server application. In this section we explain in more details how all this works. The sequence of communication between the 3 main layers of the application can be viewed in figure 5.2.

The request cycle starts when a user or a client requests a page or a resource in the application. This request, just like all requests, is first of all handled by the application Dispatcher. The Dispatcher is an object whose main functionality is to convert all requests into controller actions. It uses the dispatched request to locate and load the correct controller. This is actually the use of the Front Controller pattern, which provides a centralized entry point for handling requests [20].

When the controller received the request, it may communicate with the Model Layer to retrieve, modify or save data in case of need.

After that, the controller will proceed to delegate to the correct view object the task of generating output resulting from the data provided by the model.

Finally, when this output is generated, it is immediately rendered to the user.

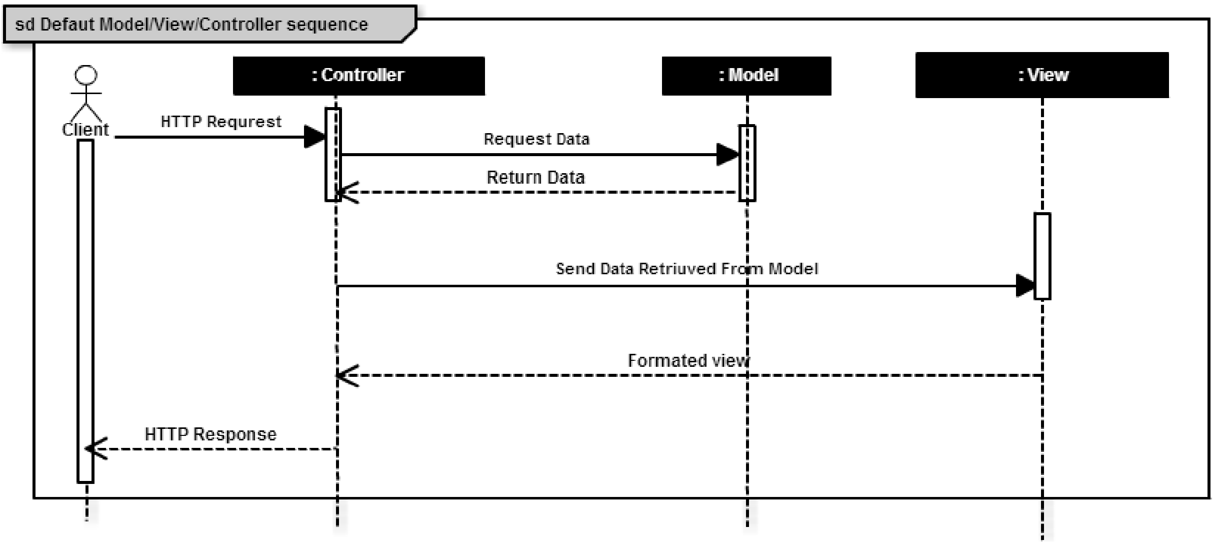


Figure 5.2: sequence diagram – request cycle

5.2.6 Routing

Routing is a feature that maps URLs to controller actions. The application routing is handled by the CakePHP Dispatcher. The Dispatcher allows specifying the name of the controller and the action to be performed by this controller directly in the URL.

The URL pattern format is:

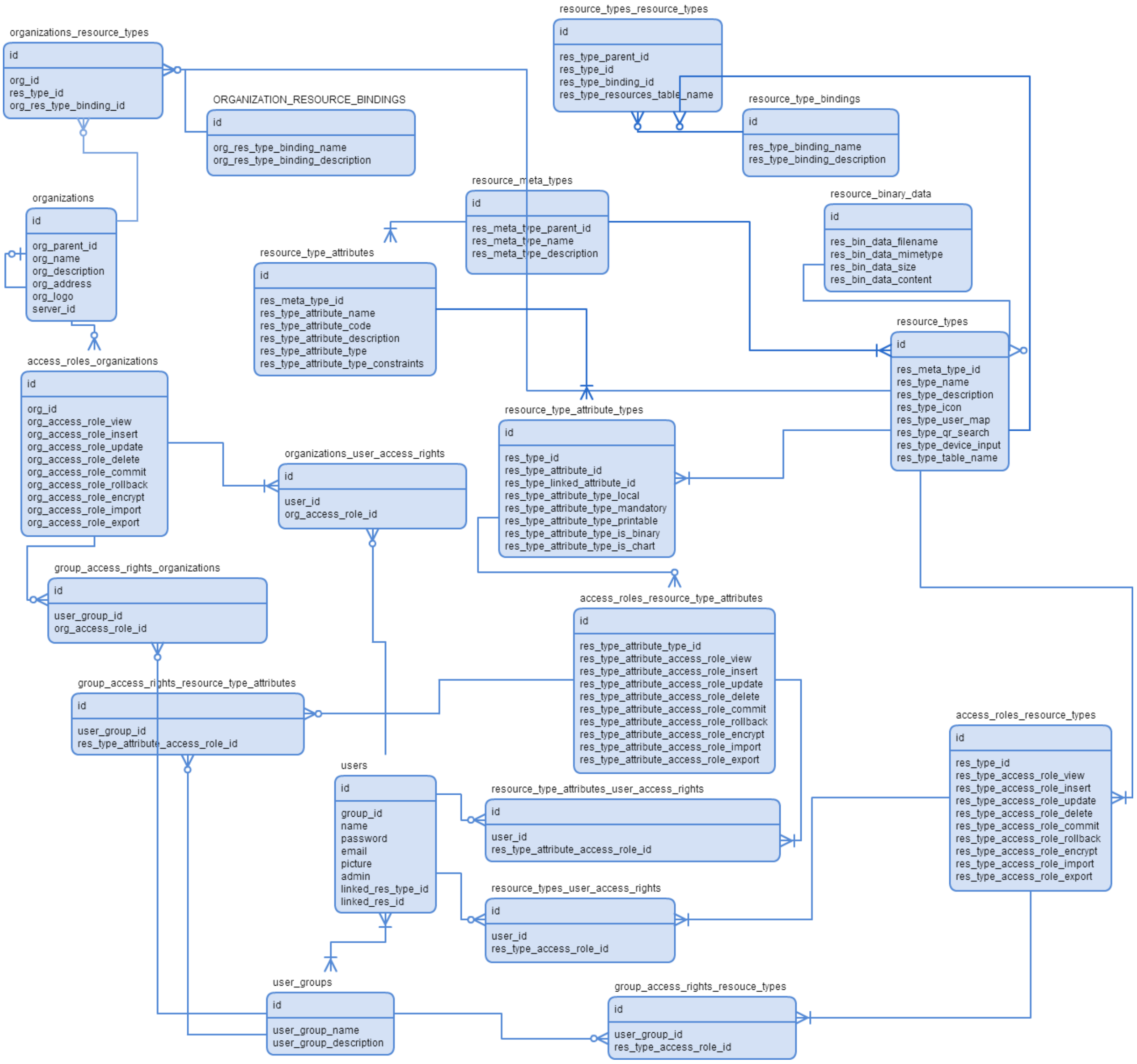
```
http://servername.org/controller/action/param1/param2/param3
```

For example, the URL /resourcetypes/view maps to the view() action of the ResourceTypesController, and /resources/add_binding maps to the add_binding() action of the ResourcesController. If no action is specified in the URL, the index() method is assumed.

It is also possible to pass parameters to the actions using the URL. A request for /resourcetypes/view/25 would be equivalent to calling view(25) on the ResourceTypesController, for example.

5.3 Data Structure

Figure 5.3 shows the data model of the system taken from [29]. As one can notice, the data model does not map specific concepts like Patient or Physician. Instead, it contains the meta model. This is because specific Resource Types will be created dynamically, as already explained.



organizations_resource_types
id
org_id
res_type_id
org_res_type_binding_id
ORGANIZATION_RESOURCE_BINDINGS
id
org_res_type_binding_name
org_res_type_binding_description
resource_types_resource_types
id
res_type_parent_id
res_type_id
res_type_binding_id
res_type_resources_table_name
resource_type_bindings
id
res_type_binding_name
res_type_binding_description
organizations
id
org_parent_id
org_name
org_description
org_address
org_logo
server_id
resource_meta_types
id
res_meta_type_parent_id
res_meta_type_name
res_meta_type_description
resource_binary_data
id
res_bin_data_filename
res_bin_data_mimetype
res_bin_data_size
res_bin_data_content
resource_type_attributes
id
res_meta_type_id
res_type_attribute_name
res_type_attribute_code
res_type_attribute_description
res_type_attribute_type
res_type_attribute_type_constraints
resource_types
id
res_meta_type_id
res_type_name
res_type_description
res_type_icon
res_type_user_map
res_type_qr_search
res_type_device_input
res_type_table_name
access_roles_organizations
id
org_id
org_access_role_view
org_access_role_insert
org_access_role_update
org_access_role_delete
org_access_role_commit
org_access_role_rollback
org_access_role_encrypt
org_access_role_import
org_access_role_export
resource_type_attribute_types
id
res_type_id
res_type_attribute_id
res_type_linked_attribute_id
res_type_attribute_type_local
res_type_attribute_type_mandatory
res_type_attribute_type_printable
res_type_attribute_type_is_binary
res_type_attribute_type_is_chart
organizations_user_access_rights
id
user_id
org_access_role_id
group_access_rights_organizations
id
user_group_id
org_access_role_id
access_roles_resource_type_attributes
id
res_type_attribute_type_id
res_type_attribute_access_role_view
res_type_attribute_access_role_insert
res_type_attribute_access_role_update
res_type_attribute_access_role_delete
res_type_attribute_access_role_commit
res_type_attribute_access_role_rollback
res_type_attribute_access_role_encrypt
res_type_attribute_access_role_import
res_type_attribute_access_role_export
group_access_rights_resource_type_attributes
id
user_group_id
res_type_attribute_access_role_id
access_roles_resource_types
id
res_type_id
res_type_access_role_view
res_type_access_role_insert
res_type_access_role_update
res_type_access_role_delete
res_type_access_role_commit
res_type_access_role_rollback
res_type_access_role_encrypt
res_type_access_role_import
res_type_access_role_export
users
id
group_id
name
password
email
picture
admin
linked_res_type_id
linked_res_id
resource_type_attributes_user_access_rights
id
user_id
res_type_attribute_access_role_id
resource_types_user_access_rights
id
user_id
res_type_access_role_id
user_groups
id
user_group_name
user_group_description
group_access_rights_resource_types
id
user_group_id
res_type_access_role_id

Figure 5.3: Data model

Below is the description of some of these meta tables:

- resource_types: will contain information about Resource Types
- organizations_resource_types: association table that will store the relationship Organizations and Resource Types.

- resource_types_resource_types: association table that will store the Resource Type Bindings.
- resource_type_attributes: will contain store Resource Type Attributes.
- resource_type_attribute_types: will store Resource Type Attributes characteristics.

Besides these tables, there are also other tables that will contain Organizations, Users, User Groups, and Access Roles and Rights. User access rights are defined in different levels: users can have access on Resource Types and/or on their Attributes, and on Organizations. The same applies for user groups.

5.4 Implementation Details

5.4.1 Class Diagram

Model Classes [29]

The model classes form the business layer in the application. They represent data and are used to manage almost everything regarding data. This includes processing, validating, associating or other tasks related to handling data.

Each model class corresponds to a database table. A model can be associated with other models, as we can see it in figure 5.4. For example, the model class ResourceType is associated with the model class ResourceMetaType.

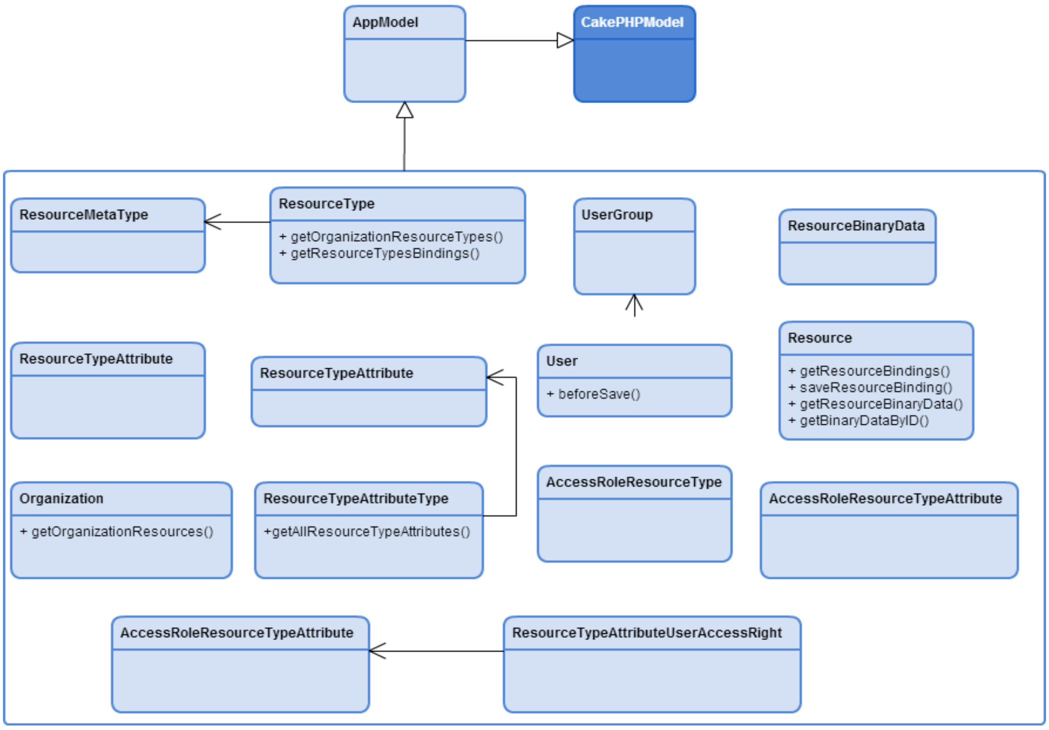

AppModel
CakePHPModel
ResourceMetaType
ResourceType
+ getOrganizationResourceTypes()
+ getResourceTypesBindings()
UserGroup
ResourceBinaryData
ResourceTypeAttribute
ResourceTypeAttribute
User
+ beforeSave()
Resource
+ getResourceBindings()
+ saveResourceBinding()
+ getResourceBinaryData()
+ getBinaryDataByID()
Organization
+ getOrganizationResources()
ResourceTypeAttributeType
+getAllResourceTypeAttributes()
AccessRoleResourceType
AccessRoleResourceTypeAttribute
AccessRoleResourceTypeAttribute
ResourceTypeAttributeUserAccessRight

Figure 5.4: Model classes

From figure 5.4 we can notice that all model classes extend the application model, AppModel, which in turn extends CakePHP' s internal model class. The CakePHP internal model comes with methods for

- retrieving data from the database, such as find(), findById(), findAllBy();
- saving or updating data into the database, such as create(), save(), saveField(), saveMany(), saveAssociated(), saveAll(), updateAll();
- and for deleting data from database, such as delete() and deleteAll().

Thanks to inheritance, all these methods are available for all model classes. By extending the CakePHP model class therefore, each model class is endowed with all the functionality it needs to create queries and to save and delete data. This helps keep the model classes clean and avoids writing multiple queries to communicate with the database. That is the reasons why the majority of the application model classes are empty (contain simply the declaration, but have no methods).

However, in some cases, a model class may need specific queries that are not available in the inherited methods. In this case, we can define a method that will perform the needed queries. This is the case for the model class Resource. Besides the inherited methods, it implements its own methods: getResourceBindings(), saveResourceBinding(), getResourceBinaryData(), getBinaryDataByID().

The application model class, AppModel, is used as the intermediate class between all model classes and the CakePHP internal model. For now it is empty. But the idea of having the AppModel is to have a possibility to define functionality that should be made available to all models within the application.

Controller Classes

Controller classes are kind of middle man between the Model and View layers. After routing has been applied, the Dispatcher chooses the correct controller to process user's or client's request.

Controllers provide a number of methods that handle requests. These are called *actions*. Each public method in a controller is an action, and is accessible from a URL. An action is responsible for interpreting the request and creating the response.

Figure 5.5 shows all the controllers of the server application. As we can see, controllers don't talk to each other. They even ignore the existence of each other. This does not apply for the AppController: this class is the parent class to all the application's controllers, meaning that all application controllers extend the AppController class. AppController itself extends the controller class included in the CakePHP core library. As in the case of models, the inheritance of the CakePHP core controller allows the application controllers to use CakePHP functions available in the core controller. This prevents us from writing some boilerplate code we would otherwise need to write.

As already stated, controller classes do not communicate between them, but each controller can use its corresponding model. When the model name matches that of the controller, this model is automatically made available for access and the controller can directly use it. For example, the controller ResourceTypesController will automatically initialize the ResourceType model.

But the controller can also load other models and use any component class (see the next section).

In the class diagram of figure 5.5, one can notice that most of the controllers have a method called beforeFilter(). This is one of the callback functions provided by the CakePHP core controller, used to insert logic around the request life-cycle. This function is executed before every action in the controller. We use it especially to control the user access. So, before processing the user request, we first control in this method if he has access to the resource is requiring or not.

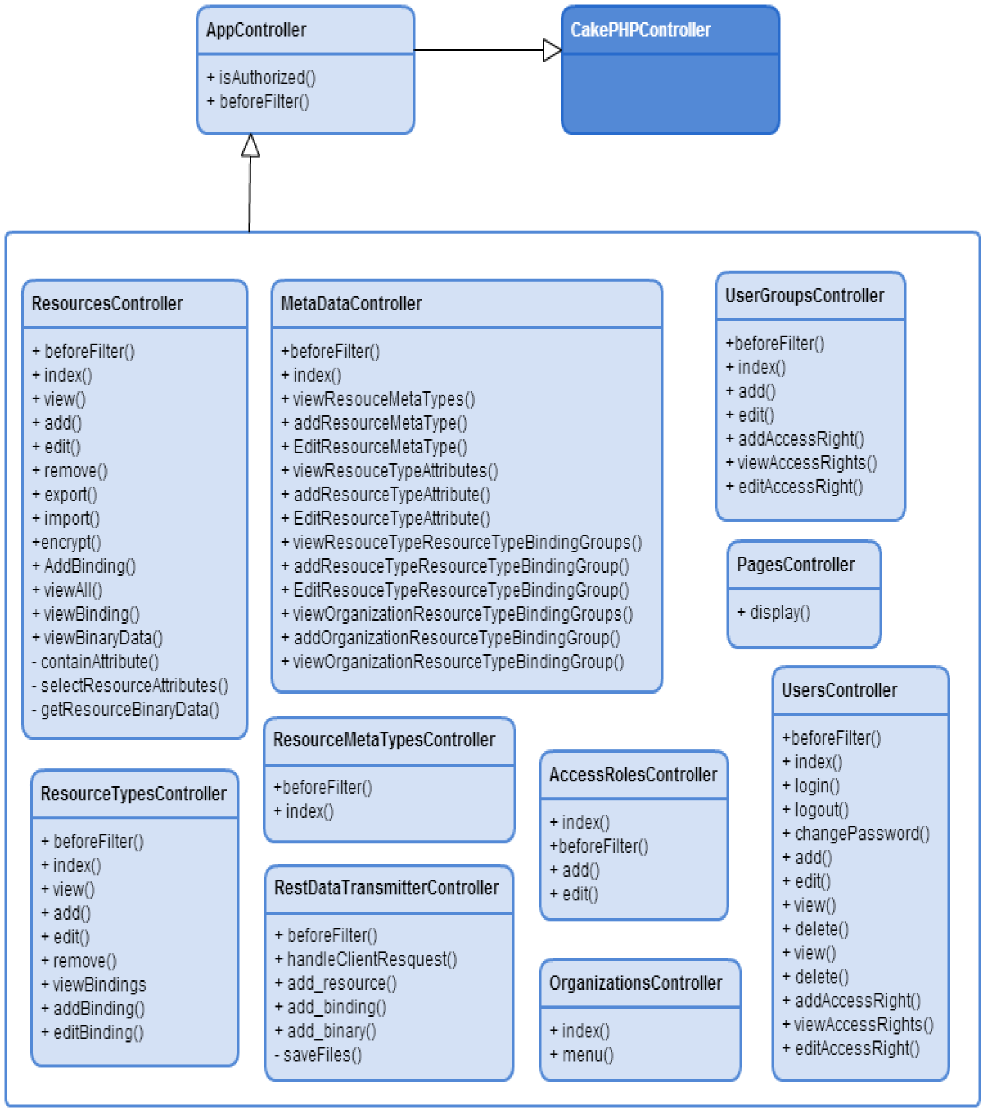


Figure 5.5: Controller classes

Component Classes

Component classes are functions that are shared between controllers. They are best used for code that is used in many (but not necessarily all) controllers.

In the application we implement for now two components, as show in figure 5.6: the *ResourceNameSolverComponent* and the *AuthorizedComponent*. The first one is used to manage the naming convention. Given a Resource Type name, this component is able to render the exact name of the database table of this Resource Type and also the model class representing this Resource Type. It does so by applying the naming convention rules (see the section Naming Conventions for more details).

The *AuthorizedComponent* is used to ensure the application authorization. Concretely, it is used to determine if the identified/authenticated user is allowed to access the resources they are requesting.

In addition to these two components, the application also uses the components provided by the framework, such as Pagination, Sessions, Authentication, Security and Request Handling.

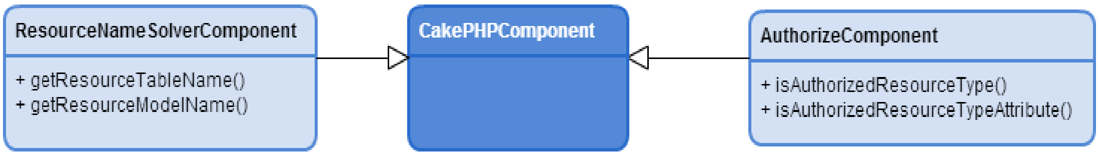

ResourceNameSolverComponent
+ getResourceTableName()
+ getResourceModelName()
CakePHPComponent
AuthorizeComponent
+ isAuthorizedResourceType()
+ isAuthorizedResourceTypeAttribute()

Figure 5.6: Component classes

Helper Classes

Helpers are the component-like classes for the presentation layer of the application. They contain presentational logic that is shared between many views.

Figure 5.7 shows the application Helper sub layer. Just like models extend AppModel and controllers extend AppController, all helpers extend a special class, AppHelper, which in turn extends the CakePHP Helper class.

The application implements just one helper class called TreeHelper. This helper is used to display Organizations in hierarchic order, i.e. in a tree-like structure.

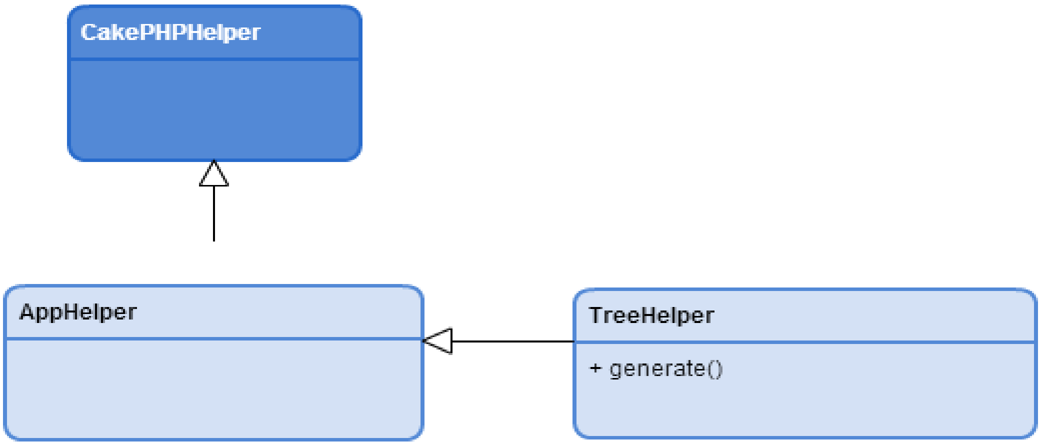


Figure 5.7: Helper classes

5.4.2 Implementation of the Dynamic Model

As stated in chapter 4 of this document, the system we are building is supposed to be generic. That is the reason why in all class diagrams and in the database model described in the previous sections, there is no specific concepts or objects such as Patient, Physician, Nurse, Diagnosis, etc. All these are supposed to be created dynamically by the system owner (Organization).

That means that the system is a kind of a global meta model, and organizations have to create their own instance of the system to fit their needs.

In other words, how can a system admin create an instance of the system? In this section we explain how all this can be done. We will describe the way Resource Types can be created and how the system allows managing the dynamically created Resource Types.

The process follows the following steps:

Creating Resource Types

First the admin has to create the needed Resource Types. Let us remember that a Resource Type is a meta object used internally by the system to encapsulate specific objects, such as Patient, Physician, Device, Diagnosis, Document etc.

So, by creating a Resource Type we mean creating a specific instance of the Resource Type object. This is done by providing the following attributes:

- The id of the Organization to which the new Resource Type will belong. It is possible to specify more Organizations, has a Resource Type can be bind to more than one Organization.
- The Resource Type *Name*: for example Patient. This name must be unique in the system, because two Resource Types cannot have the same name within the system.
- The Resource Type *Description*.

- The Resource Type Attributes and their characteristics: such as Name, Age, etc.

When all the needed information is specified, the request for creating the new Resource Type is sent to the *ResourceTypesController* who is responsible for creating Resource Types. The following actions are then performed by the *ResourceTypesController*:

- Some checks are performed to make sure that the specified data are valid.
- A new database table is created. The name of the table matches the one of the Resource Type and the table columns correspond to the given Resource Type Attributes.
- A new record (new row) is inserted into the database table *resource_types*. The record contains the Resource Type name and description. This table keeps track of all Resource Types.
- New records are inserted into the database table *organizations_resource_types*, to specify to which Organizations the new Resource Type belongs.
- New rows are inserted into database table *resource_type_attribute_types*, to record the new Resource Type Attributes and their characteristics.
- A new model class is generated in the Model layer (defined in a new generated file). The name of this class corresponds to the name of the Resource Type. The created model class is empty, meaning that it contains no logic, but just the class definition, which looks like:

```
<?php

/*
  This file was generated automatically
 */

/**
 * This class represents the Resource of Type: $RESOURCE_TYPE_NAME
 *
 * @author System
 */
class $RESOURCE_TYPE_NAME extends AppModel {
   //no code is needed here
}
```

The new created class does not need to implement any logic, because it extends the AppModel, which in turns extends the CakePHP core Model. As already explained, this inheritance allows new created model class to be endowed with all the functionality it needs to manage data in the database, that means create, save and delete data etc.

That is all! The new Resource Type is created and ready to be used. No controller class is needed, because there is one controller that helps manage all the dynamically created Resource Types – the *ResourcesController* (see the third step).

Figure 5.8 shows the sequence of communication between different objects to create a new Resource Type. The *ResourceTypesController* communicates with the *ResourceType* and *OrganizationResourceType* models to create and save Resource Types.

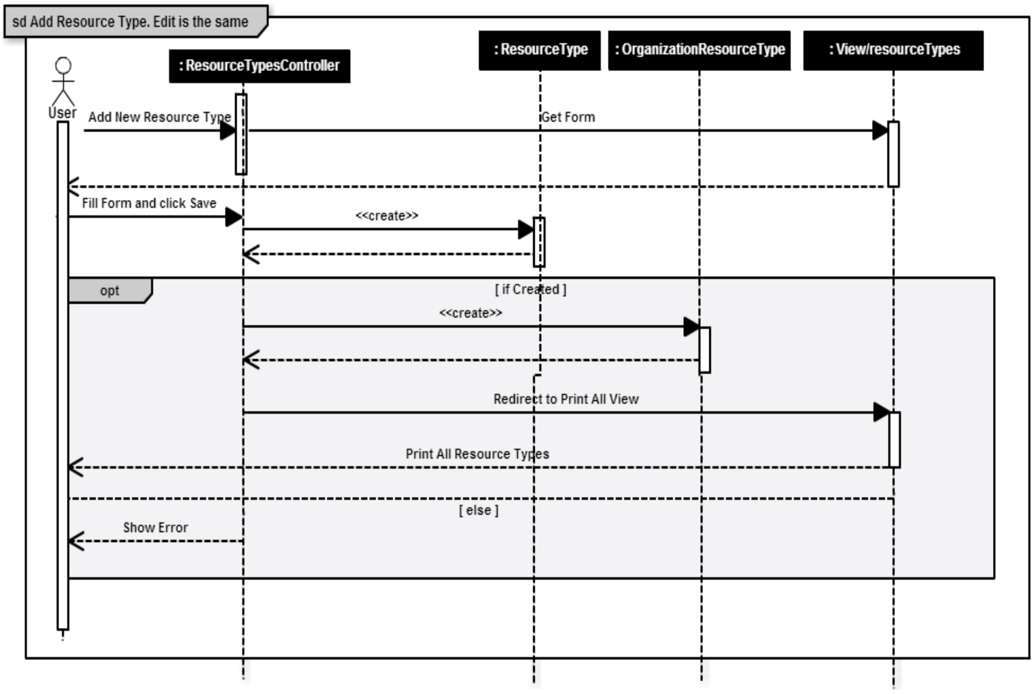


Figure 5.8: Adding a new Resource Type

Adding Bindings

After Resource Types are created, the admin may wish to define a relationship between two Resource Types. This relationship is what we call Resource Type Binding. The creation of Resource Type Bindings is also handled by the *ResourceTypesController.*

In order to define a Resource Type Binding, the following must be specified:

- The names of the two Resource Types between which the Binding has to be created.
- One of the two Resource Types has to be set has the parent of the other.

To create the Binding then, the *ResourceTypesController* performs the following:

- Make sure that this Binding does not exist in the system already.
- Create a new database table for this Binding. The name of the new table matches the name of the two Resource Types. To generate the right table name respecting the naming convention, the *ResourceTypesController* calls the *ResourceNameSolverComponent*, which applies the naming convention.

- A new row is inserted into the table *resource_types_resource_types*. The record contains the id of the parent Resource Type and the id of the child Resource Type. This helps keep track of the Resource Type Bindings.

Managing Resources

Resource Type objects are not directly known by the system (they are not part of classes modeled in the system), because they are created dynamically. Here we explain how the system manages them. This includes creating new instances of these dynamically created Resource Types (which means adding new records in the new generated tables).

This is possible thanks to the meta tables. They store information about the dynamically created tables. That is why before (or after) creating a new Resource Type, we store information about it into the meta table *resource_types*. In the same way we also save Resource Type Attributes, Resource Type Bindings into meta tables.

- ***Viewing the created Resource Types***
  All dynamically created Resource Types are immediately visible via the view () method of the *ResourceTypesController* controller class. This method accepts one parameter – the id of the Organization. So, by typing resourcetypes/view/some_existing_organization_id, the user can view the list of all created Resource Types of the given Organization (if he has access rights). What this method does is simply query on the table resource_types, where all Resource Types are stored (using of course an appropriate model to talk to the database).

- ***Viewing Records of a Resource Type***
  Viewing records from the dynamically created table is ensured by the controller *ResourcesController*, via its method viewAll(). The viewAll() method accepts the Resource Type ID as parameter. First it gets the Resource Type Name, then it tries to load the corresponding model of this Resource Type, which is then used to query on the table corresponding to the Resource Type (i.e. on the generated table).

- ***Adding a Record into a Dynamically Created Table***
  Adding records (or Resources) into a generated table is also done using the *ResourcesController* and follows the same logic. The edit also follows the same strategy.

  To add a record, the method add() of the *ResourcesController* is called. This method also accepts the Resource Type ID as parameter in order to be able to determine the right Resource Type table into which the new record has to be inserted.

  Figure 5.9 shows the message sequence chart between different objects while adding a new or editing an existing Resource.

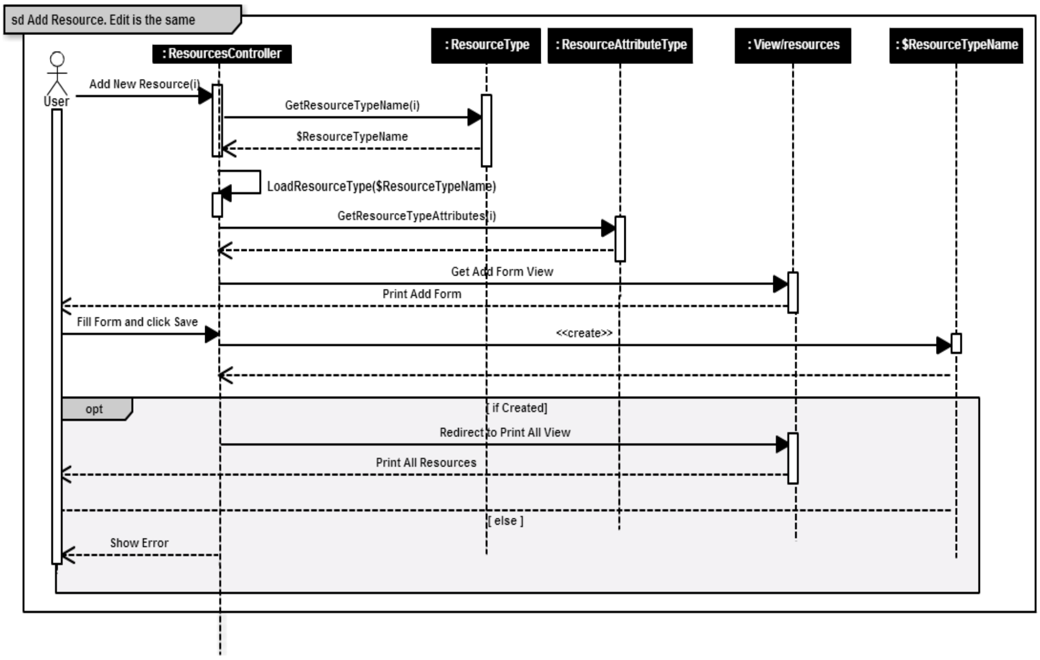


Figure 5.9: Adding a Resource

- ***View Resource Bindings***
  The *ResourcesController* allows also viewing Resource Bindings. This is done in its method viewBinding(), which accepts 3 parameters: the id of the parent Resource Type, the id of the Resource and the id of the child Resource Type.
  If for example we have created Resource Types Patient and Diagnosis and defined a Binding between them, then to view a given patient's diagnosis, the following arguments must be provided
    - The id of the Resource Type (here the Resource Type is Patient).
    - The id of the patient whose diagnosis has to be displayed.
    - The id of the child Resource Type (here Diagnosis).

- ***Adding a Binding Record***
  To add a Resource Binding (for example to add patient's diagnosis), we use the method addBinding() of the *ResourcesController()*. Just like the viewBinding() method, the addBinding() also accepts 3 parameters: the id of the parent Resource Type, the id of the Resource and the id of the child Resource Type.

  In figure 5.10, we can see the sequence of interactions between ResourcesController and other objects when adding a new Resource Binding.

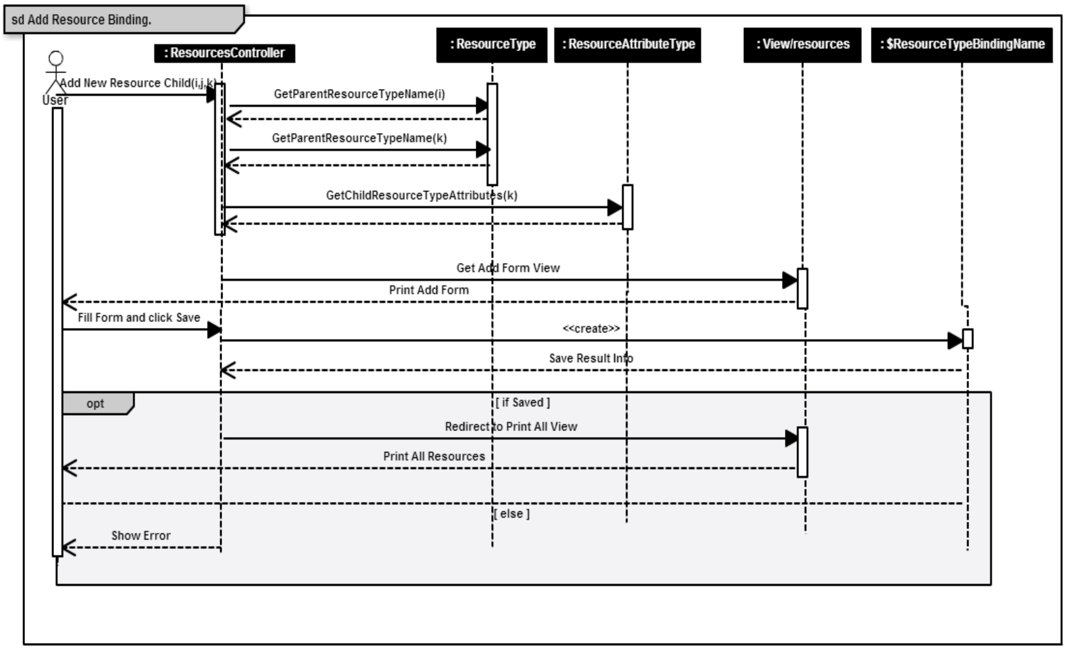


Figure 5.10: Adding a Resource Binding

Naming Conventions

From the above section, we have learned that to be able to retrieve data in the dynamically created tables, the application used the information stored in the meta tables. That means that the application first gets the Resource Name from a meta table, which allows it then to query on the dynamically created table using that name.

For all this to work properly, it is necessary to respect certain conventions when it comes to naming such tables. This is very crucial, as the application relies on the correct table names, to be able to work with it.

To achieve this, a couple of rules are necessary. In this section we define those rules and explain how they are implemented.

- **Model Naming**
  As already stated, model class names are singular and CamelCased. The model name is important, as it corresponds to a database table. This “correspondence” is made possible by using the model class name.
- **Resource Type Table Naming**
  Table names corresponding to models are plural and underscored.
  Examples of conventional model and corresponding table names are shown in the following table:

Model Name	Table Name
Patient	patients
MedicalProblem	medical_problems
HeartRate	heart_rates

Table 13: example conventional model and table names

Table field names are also singular. The table fields with two or more words are underscored. For example: First Name => first_name; ID Number => id_number.

- **Resource Type Binding Table Naming**
  Resource Type Binding tables are used to map relationships between Resource Types. They must be named after the model tables they will join, arranged in alphabetical order (medical_problems_patients rather than patients_medical_problems).
  Here are some examples:

Table Name 1	Table Name 2	Binding Table Name
patients	medical_problems	medical_problems_patients
patients	heart_rates	heart_rates_patients
organizations	resource_types	organizations_resource_types

Table 14: example conventional binding table names

These convention rules must be respected when creating a Resource Type and when trying to retrieve information stored in the dynamically created model. All this is solved by the component *ResourceNameSolverComponent*, which implements algorithms allowing determining the right model and table names according to the above defined rules.

This component implements a couple of methods, among which we can mention:

- ***getResourceTableName*(): **accepting a Resource Type name as parameter, this method returns the corresponding table name. For example, if the argument is *Patient*, the method will output *patients*. The output will be the same if the given Resource Type name is *patient*, *patients* or *Patients*. The input *Medial Record* will have as output *medical_records*.
- ***getResourceModelName*(): **this method also accepts a Resource Type Name as parameter an returns the corresponding model name. For the input *Medical Record* (or *medical record*), the method will produce *MedicalRecord*.
- ***getResourceBindingTableName*(): **This method accepts two parameters – the parent Resource Type name and the child Resource Type name, and returns the corresponding binding table for the two Resource Types.

Note: these conventions assume that used names would be in English.

5.5 Security

The server ensures data security in different levels:

Authentication

Each user interacting with the system (remotely via a client or not) must login by providing valid password and login. The user password is encrypted *bcrypt*, a key derivation function that a salt per user to protect against rainbow table attacks.

Authorization

The authorization can be specified for each Resource Type and also for each attribute of a Resource Type. For each Resource Type/Resource Type Attribute, the following access rights can be defined:

- View: defines access for viewing a Resource Type/Resource Type Attribute
- Insert: access for adding new records
- Update: access for updating
- Delete: access for deleting
- Encrypt: access for encrypting
- Import: access for uploading data
- Export: access for exporting data

This offers security and respects at the same time our requirement N3 defined in chapter 2, about flexibility. Indeed, instead of deciding who has access to what, the system organizations define their own access roles, according to their needs.

Secure data transport

When communicating with the clients, the server used HTTPS protocol, which uses SSL to encrypt data.

Data are encrypted

All patients' data are encrypted and saved into database. Saving data into database allow effective access control on them.

Chapter 6

Implementation of a Method for Patient Data Acquisition

In this chapter, we discuss the implementation of a low-cost method for patient physiological data acquisition. Our focus is to provide patients with a system allowing them to measure their heart rate and to be able to send it to their help professionals.

We start the description of the implementation by first providing an overview of physiological signals and different methods used to measure heart rate.

6.1 Overview of Physiological Data

Human body is constantly communicating information about a person's health state. This information is defined by variety of physiological parameters, such as heart rate, blood pressure, oxygen saturation levels, blood glucose, nerve conduction, brain activity and so forth. [23, 24]

Many instruments have been developed to capture those physiological parameters, such as sensors placed on the body or implanted. These measurements provide useful information upon which clinicians can make decisions.

However, not all physiological parameters are informative and can be used to evaluate patient's health state. Moreover, the measurement of some of them may require special conditions and expensive medical equipment and materials. [23]

It has been suggested that assessing the cardiovascular and respiratory systems by measuring heart rate, respiration rate, temperature, and blood pressure provide significant insight in patient health state [23].

The so-called vital signs are useful in detecting or monitoring medical problems. Let us see in more detail the methods used for measuring human heart rate.

Heart Rate Monitoring Methods

To monitor heart rate, two primary technologies are available to device manufacturers: ECG (Electrocardiography) and PPG (Photoplethysmography).

ECG or Electrocardiography is a representation of the electrical activity of the heart over a period of time using electrodes placed on a patient's body. Just like other muscles, cardiac muscle contracts in response to electrical depolarization of the muscle cells. The sum of this electrical activity, when amplified and recorded, is what we call ECG. [25]

PPG or Photoplethysmography is a light-based technology to sense the rate of blood flow as controlled by the heart's pumping action. The technology consists of a light source and a detector, with red and light-emitting diodes (LEDs) commonly used as the light source.

The PPG sensor monitors changes in the light intensity via reflection from or transmission through the tissue. The changes in light intensity are associated with small variations in blood perfusion of the tissue and provide information on the cardiovascular system, in particular, the pulse rate. [25]

A photoplethysmographic waveform is made of two components, as shown in figure 6.1: the Direct Current (DC) component corresponding to the detected transmitted or reflected optical signal from tissue and venous blood, and the Alternating Current (AC) component that shows the changes in blood volume that occurs between the systolic and diastolic phases of the cardiac cycle. [27]

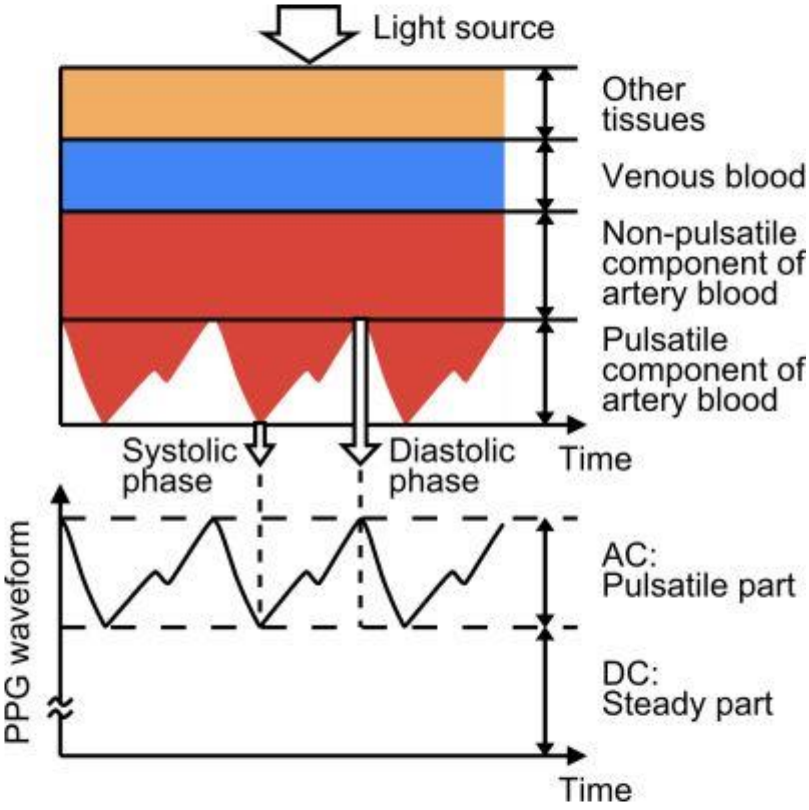


Figure 6.1: Variation in light attenuation by tissue (taken from [27])

6.2 Hardware Prototype

In order to monitor patient’s heart rate, we use the PPG (Photoplethysmography) method, instead of ECG, because it is cheaper and simpler than ECG [26].

As figure 6.2 shows, the hardware prototype we propose will allow a patient to measure its heart rate using the Pulse Sensor which is connected to the Arduino board, connected itself to the computer via USB- AB connector. The following components are used:

- A pulse sensor called *Pulse Sensor Amped.*
- Arduino Duemilanove board with the microcontroller ATmega328.
- And a USB A-B cable for serial communication.

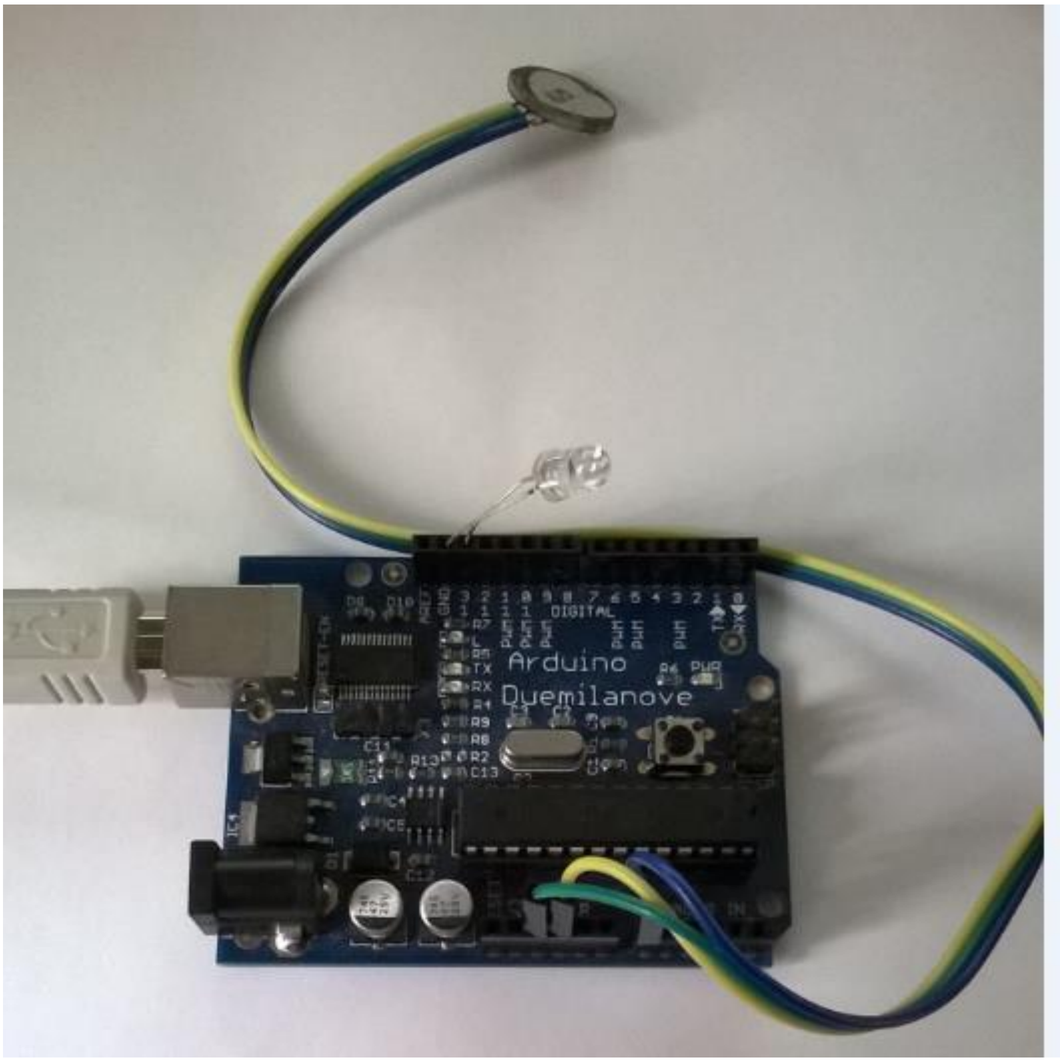


Figure 6.2: Components used for the hardware prototype

This solution is low-cost and does not require many components. The Pulse Sensor costs $24.99, the Arduino board around $21.16 and the USB A-B cable around $4

The board can operate on an external supply of 6 to 20 volts, but the recommended range is 7 to 12 volts [34].

The Pulse Sensor has a 24” flat color coded ribbon cable with 3 male header connectors (+3V to +5V, GND and Signal). The connection to the Arduino board is done as (figure 6.3):

The Signal wire is connected to the Arduino A0 analog pin

The +5V wire is connected to Arduino +5V pin

The GND is connected to Arduino GND pin

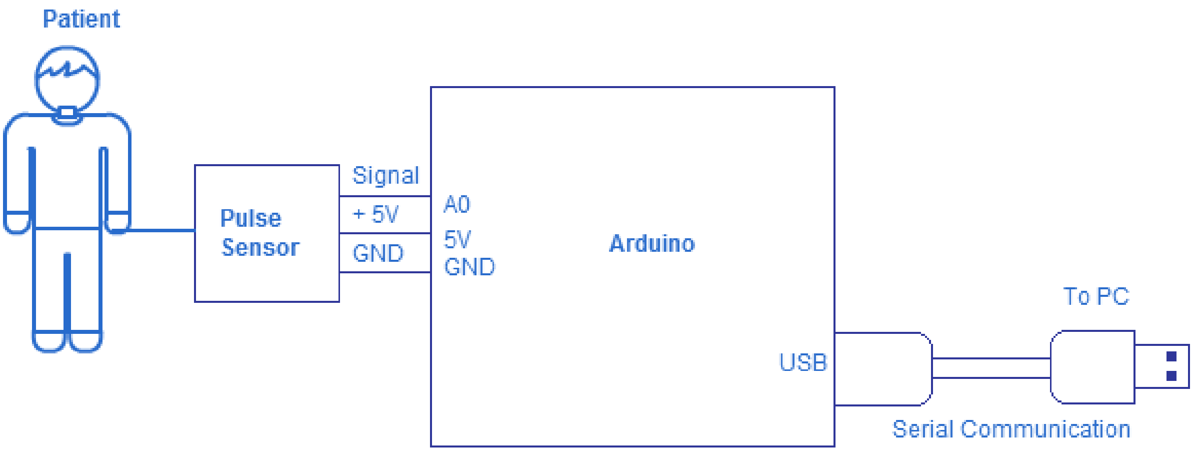


Figure 6.3: Measuring patient's heart rate

When all these connections are done, the microcontroller starts immediately sampling. The samples are sent to the PC via serial communication and can be viewed or saved into a file using a serial port terminal (COM), such as RealTerm or Tera Term. Data saved in a file can then be sent to the server using the client application (this process is described in the next chapter).

The sampling frequency is set to 500 Hz, which gives us a high enough resolution to get reliable signal28].

The pulse sensor we use is a photoplethysmograph and produces an analog fluctuation in voltage. It amplifies the raw signal and normalizes the pulse wave around V/2 (512V).

When the amount of light on the sensor remains constant, the signal value will remain at 512V (midpoint of ADC range). But if there is more light, the signal goes up. With less light, the opposite appends. Light from the green LED, that is reflected back to the sensor changes during each pulse. [28]

6.3 The Signal Processing Algorithm

Even though the signal coming from the Pulse Sensor is amplified, we have still to clean it from external noise in order to get a cleaner signal. To do that, we use the algorithm described below.

Before viewing this algorithm, let us first see how the heart rate waveform looks like. This is shown in figure 6.4. When the heart pumps blood through the body, there is a pulse wave that travels along all arteries to the very extremities of capillary tissue where the sensor is attached. This produces a rapid upward rise in signal value (peak). [28]

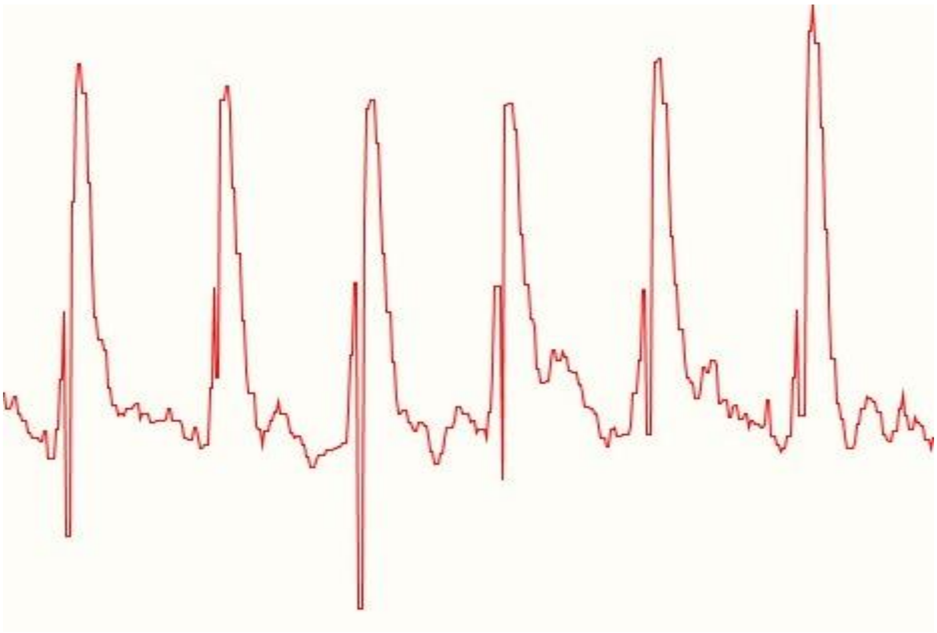


Figure 6.4: Example of a PPG waveform

What we want to do is to find successive moments of instantaneous heart beat and measure the time between, called the Inter Beat Interval (IBI). Having the IBI, we can then compute another important parameter called BPM (beats per minutes). This can be done by following the predictable shape and pattern of the PPG wave.

There exists many methods allowing finding the instantaneous moment of heart beat. Some choose the upward rise event (the peak); others say it is better when the signal gets to 25% of the amplitude, and finally certain researchers think is 50% of the amplitude. [28] We have tried all these methods, and found out that better results were in our case observed while measuring the IBI by timing between moments when the signal crosses 50% of the wave amplitude.

The algorithm looks like this [28]:

Algorithm 1: Process the Heart Rate Analog Signal

```
Signal ← Read Analog Signal from Sensor
time ← time + 2                    // time between two signals: 2 ms
interval ← time - lastTime;        // time since the last beat to avoid noise


IF Signal < Trough AND interval > (IBI/5)*3) AND if Signal < Trough THEN // avoid noise
    Trough ← Signal // remember the lowest point in pulse wave
END IF
```

```
 7:    IF Signal > T AND Signal > Peak THEN
 8:         Peak ← Signal // remember the peak
 9:    END IF
// here we assume the signal is good
10:    IF interval > delay1 AND Signal > T AND Is_a_heart_beat = false AND interval > 3/5 of IBI THEN
11:    IBI ← time – lastTime // Inter-Beat Interval (the time between beats)
12:    BPM ← ComputeBPM (IBI) // Beat Per Minute (this is our famous heart rate)
13:   SendDataToSerial (Signal, IBI, BPM) // send the signal via serial communication
14:  END IF
 // after the heartbeat, values go down
15:  IF Signal < T and Is_a_heart_beat = true THEN
16:      Is_a_heart_beat ← false
17:      amplitude ← Peak - Trough
18:      T ← amplitude/2 + Trough // set T at 50% of the amplitude. We can try also 25%
19:      Peak ← T
20:      Trough ← T
21: END IF
// if after certain delay there is no heartbeat, we reset values
22: IF N > delay2 THEN
23: Reset all parameters to their default values
24: END IF
```

After reading the signal from the sensor (line 1), we compute time since the last valid beat and try to make some controls and make sure that the signal is really a heartbeat.

In lines 5 and 8 we keep track of the highest and lowest values of the PPG wave (Peak and Trough) in order to get the accurate amplitude, which we compute in line 18.

To avoid noise, there is a time period of 3/5 IBI that must pass before we compute the Trough (line 4). In line 10 we can see that there is another time period that must pass before we look for a valid heartbeat, in order to avoid high frequency. This time period can be for example 250 milliseconds (which is equivalent to a maximum of 240 BPM).

After that delay, if the *Is_a_heart_beat* Boolean parameter was set to false, then we know that we have a heartbeat. We can then compute the BPM and send the signal via the serial port. Note that the function implementing this algorithm must be called every 2 milliseconds (as described in the previous section).

The BPM is derived every beat from an average of the previous 10 IBI times. We compute it by using the following algorithm.

Algorithm 2: ComputeBPM (IBI)

```
Is_a_heart_beat ← true
lastTime ← time
total ← 0
N ← 10
FOR all i = 0 : N -2 DO
    rate[i] ← rate[i+1]
    total ← total + rate[i]
END FOR
rate[N - 1] ← IBI
total = total + rate[N - 1]          // add the latest IBI to total
total /= N               // average the last 10 IBI values
BPM ← 60000/total
RETURN BPM
```

These algorithms are directly implemented on the microcontroller using Arduino development environment (IDE). This IDE is free and easy to use. The next chapter describes how to send the measured data (but not only) to the server.

Chapter 7

Implementation of the Client for Sending Patient Data

Because the server is using a standard protocol HTTP (HTTPs) and JSON format for the communication with client applications, the client can be whatever that supports this protocol and format. It can be a Web, Desktop, or Mobile application; it can be implemented using PHP, Java, etc.; it can run on Windows, UNIX, or other Operating Systems. Also, because the server is programmed to support dynamic creation of resources, there may be many clients, each being specialized in sending specific resources to the server using the communication protocol described in chapter 4.

All this means that the server is ready to communicate with different clients, and this is what we wanted: develop a central component (server) and allow different types of clients to communicate with it. What this means for organizations that will use the system is that they have the possibility to develop different clients according to their needs to share data with the server. The proposed architecture allows client application to be divers and simple. Any application supporting HTTP control can communicate with the server by using the IP defined in chapter 4. It can be for example a simple web form installed in patient's PC or mobile phone, or another telemedicine application such as OpenEMR

That said, in this work we implement a PHP web-based client to allow users to send binary data to the server. The objective of this client is double: test the server functionalities to make sure it does well its work, and serve as a prototype that will help in the implementation of other clients.

The client is also implemented using the CakePHP framework. The principles of the implementation are therefore the same as in the case of sever (see chapter 5). That is why we will not repeat these implementation details here. Instead, we will focus on how the client works, and how users can collect and send their data to the server.

The client is simple and does not have any data structure. It does not communicate to any database. It implements the following functionalities: allowing users to log in, collecting user data using a web form, sending data to the server, handling server's response. This chapter describes all these functionalities in detail.

7.1 Login to the Application

To be able to send data to the server, the user must be authenticated. Before the client application shows the form for the user to input its data, it first tells the user to login. However, it does not authenticate the user but let the server do the authentication. This is because the client does not have any database to compare user credentials. Hence, when the user log in, the client application simply remembers (saves into Session) the user's password and login and will use them later when contacting the server to send data for state-less communication.

7.2 Collecting and Sending Data to the Server

As already mentioned, this client is designed to send binary data (files) to the server. To do so, the client proposes a form to load the file to be sent to the server. When sending data, the following must be provided by the user via the form:

- The name of the *Resource Type* (i.e. Patient, Diagnosis). This must match the name of an existing Resource Type in server's side.
- The *Resource ID*. In case of Resource Type Patient, for example, this will be the patient's id.
- The *Resource Type Attribute* name. This also must match the name of an existing Resource Type Attribute name in server.
- Load the *file* containing data to be sent.

All this depends on Resource Types that have been created in server. If for example the server has a Resource of type Patient with attributes Document, HeartRate, and Picture and all have a characteristic of been binary, the user can send patient's document, heart rate or picture. The parameters will be in this case:

- Resource Type name: Patient.
- Resource Type id: 12344.
- Resource Type Attribute name: Document or HeartRate or Picture.

Once data are specified, the client proceeds by preparing the request to be sent to the server. The request will have the format described in chapter 4, and will look like:

```
{"data":[

{"resourceType":"Patient"},

{"resourceID":"12344"},

      {"file":[
        {"attributeCode":"Picture",
           "filename":"picture1.txt",
           "type":"text",
           "size":"58096",

     "content":"23s84weeej4smndjd09emsjdaszzzzxxxxpoe9982njd-
0sdsdsdksdj8uuennenn7ee7766636636hgbnssnndddndnddgbddny09983ndjdndndndn
dnkjshdkjsdhsjkdhjkdhjksdhjksdhkjshdkjn[psdnd’]]ddddsdsdsdsdsdsd9e8snsd
jsdjsddddddddddddddddddddddddddjjnndedjdjdjdjd"}]}

]}
```

Concretely, the client will extract information concerning the file (name, type and size), transform the file content into a text using 64base transformation, and finally encode all this into JSON format. That will form the body of the request.

In the header, the client must also specify the user credentials (login and password) for the authentication. That is all, data can be now sent to the server. The next step is to handle server's response.

7.3 Sending Patient Pulse Rate

The process for sending patient's heart rate is exactly the same as described in the previous section. The appendix A contains a User Manual describing how to measure pulse rate and save the measured samples into a file. Because patient's heart rate data is saved into a file, sending it to the server is the same as sending any other file to the server.

After sending pulse rate data to the server, it is expected that the server will print it as a chart for a physician or a clinician to view it and evaluate the patient's health state. Below is the description of this process.

Viewing Patient's Pulse Rate

Each Resource Type Attribute defined in server has a sub-attribute or characteristic called *is_chart,* whose value can be either 0 (false – default value) or 1 (true). When its value is set to 1, the server will automatically provide a button "View Chart" to print it as a graph. This is ensured by the server's Controller *ResourcesController*, in the method *viewBinary*. This method expects data containing in file to be in array, with the following format:

```
[series1, series2, series3, …]
```

And each data series is consist of values of x axis and y axis.

```
[x, y]
```

Put it all together, data will be in the following format:

```
[ [x1, y1], [x2, y2], [x3, y3], [x4, y4] ]
```

But sometimes the value of y is known or is constant and there is no need to specify it. In this case, the following format is also acceptable:

```
[ x1, x2, x2, x3, x4, x4]
```

When there are too many samples (i.e. more then 500), data will be automatically divided into smaller arrays and will be displayed progressively. The user can update a chart periodically to get a real-time effect by using a timer to insert the new data in the plot and redraw it. Time between updates is specified in milliseconds.

Heart rate samples measured by the Pulse Sensor as described in previous chapter are saved in a file in the above format, i.e.: [[x1, sample], [x2, sample], [x3, sample], [x4, y4 sample], where sample is either the Inter-Beats Intervals (IBI) or Beats Per Minutes (BPM) and x timestamp.

7.4 Handling Server's Response

After sending data to the server, the client expects the server to send some feedback. The server's response in this case contains essentially a status code, such as described in table 11. One of the client's tasks is to receive and interpret the server status code. The following rules apply when it comes to interpreting status codes:

- If the code is in the range of 200-299, this means that everything is OK (especially when the status code value is 200). The client then lets the user know by printing a OK message:
  OK! Data successfully sent.
- If the code is in the range of 400-499, there is an error in client's side (forbidden, user not authenticated, not allowed, bad request, etc.). The client prints an error message: **Oops!** The server could not process your request. It seems like there is something in your request that the server does not like. Here is what he said: bad request.
- When the code is between 500 and 599, this means that an error occurred in server's side. In this case, the client also prints an error message:
  Oops! It seems like the server encountered a serious problem while processing your request. Please, try it again later

Chapter 8

Testing

8.1 Testing the Dynamic Aspect of the System

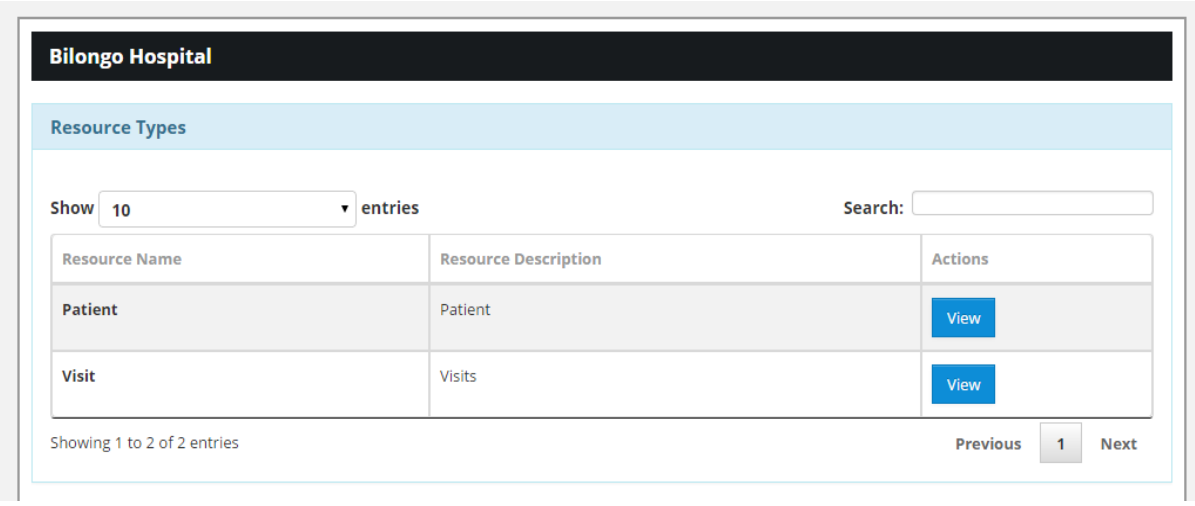
The objective of this testing is to test that the system is really dynamic and can be customized to fit the needs of different Organizations. To do that 3 different Organizations have been created: *Bilongo Hospital*, *Central Hospital Yaoundé* and *Veterinary Hospital*. For each Organization data has been added as follow:

First Organization: for the testing *Bilongo Hospital* Organization, the following Resource Types are created:

- *Patient*, with attributes: *ID, First Name, Last Name, Birth Date, Birth Place, ID Number, Address, Gender, Age and Grade,* and binary attributes: Pictures, Documents, Heart Rate.
- Visits, with the following attributes: ID, Date, Time, Description

Then a binding has been created between Patient and Visit, where Patient has been set as the parent Resource Type.

Figure 8.1 shows the two Resource Types displayed by the system.



Bilongo Hospital

Resource Types

Show 10 entries Search:

Resource Name	Resource Description	Actions
Patient	Patient	View
Visit	Visits	View

Showing 1 to 2 of 2 entries

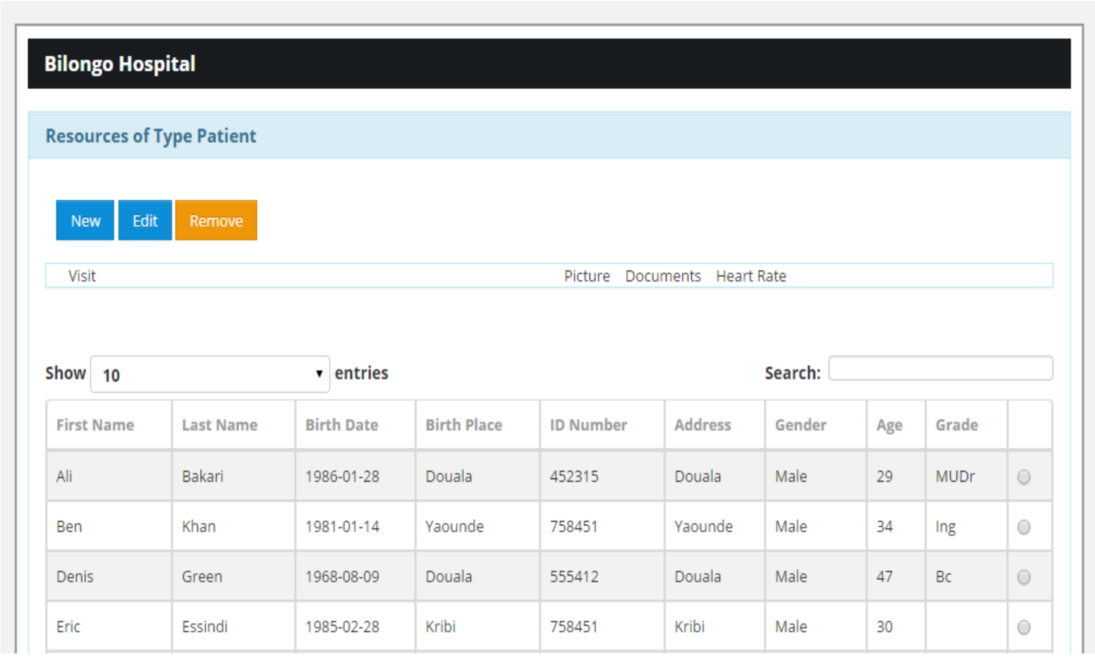
Figure 8.1: Testing Resource Types for "*Bilongo Hospital*" Organization.

The following functionalities have been tested:

- Creating new records: new patients and visits where created.

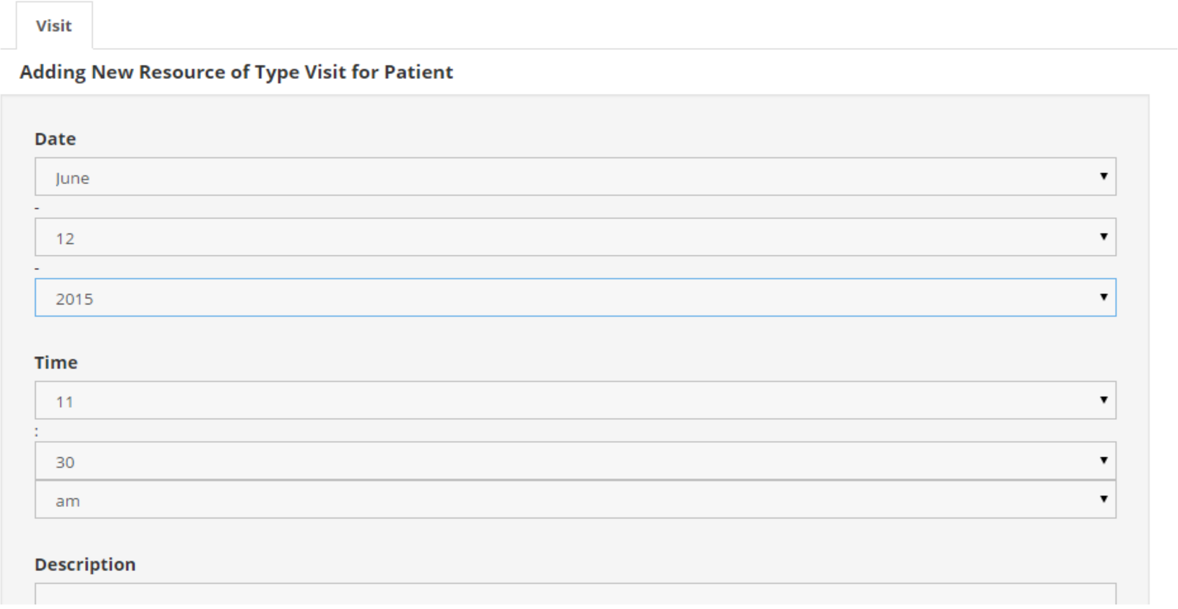
- Viewing records: the created patients/visits could be viewed
- Editing a record: created patients/visits were edited.
- Removing: some created patients/visits were removed.
- Bindings: visits were assigned to patients.

  All tested system functions worked as expected. The following figures show the screenshots realized while testing.



First Name	Last Name	Birth Date	Birth Place	ID Number	Address	Gender	Age	Grade	
Ali	Bakari	1986-01-28	Douala	452315	Douala	Male	29	MUDr	○
Ben	Khan	1981-01-14	Yaounde	758451	Yaounde	Male	34	Ing	○
Denis	Green	1968-08-09	Douala	555412	Douala	Male	47	Bc	○
Eric	Essindi	1985-02-28	Kribi	758451	Kribi	Male	30		○

Figure 8.2: Created patients in “*Bilongo Hospital*” testing Organization.



Adding New Resource of Type Visit for Patient

Date

June - 12 - 2015

Time

11 : 30 am

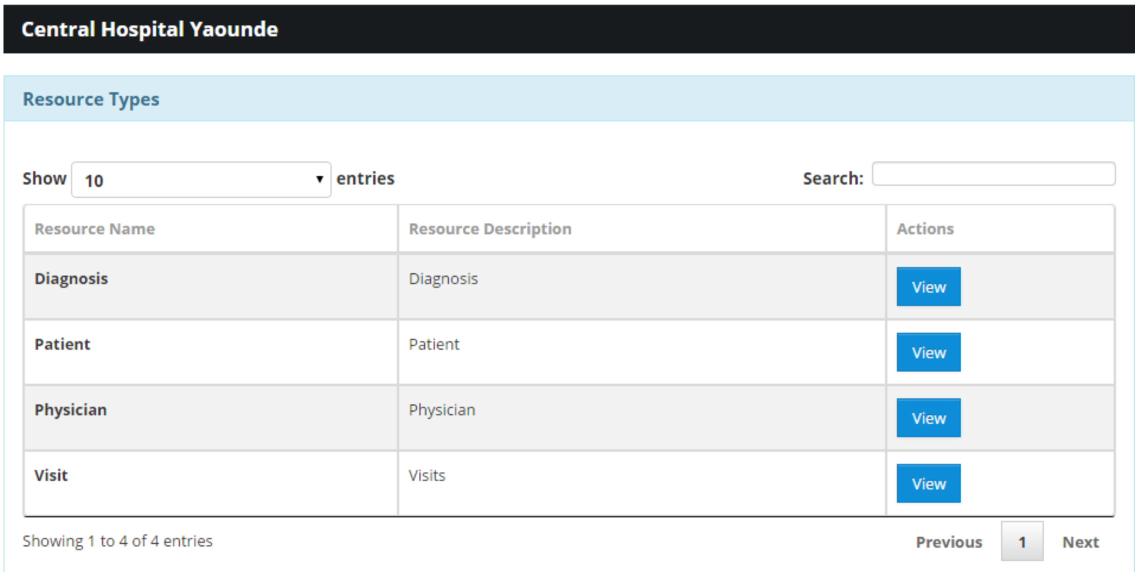
Description

Figure 8.3: Adding a visit for a given patient.

Second Organization

For the first Organization (*Central Hospital Yaoundé*) we have created the following Resource Types:

- *Patient*, with the same attributes described previously.
- *Diagnosis*, with the following attributes*: ID, Name, Code, and Type*.
- *Physicians*, with the following attributes*: ID, First Name, Last Name.*



Central Hospital Yaounde

Resource Types

Show 10 entries

Search:

Resource Name	Resource Description	Actions
Diagnosis	Diagnosis	View
Patient	Patient	View
Physician	Physician	View
Visit	Visits	View

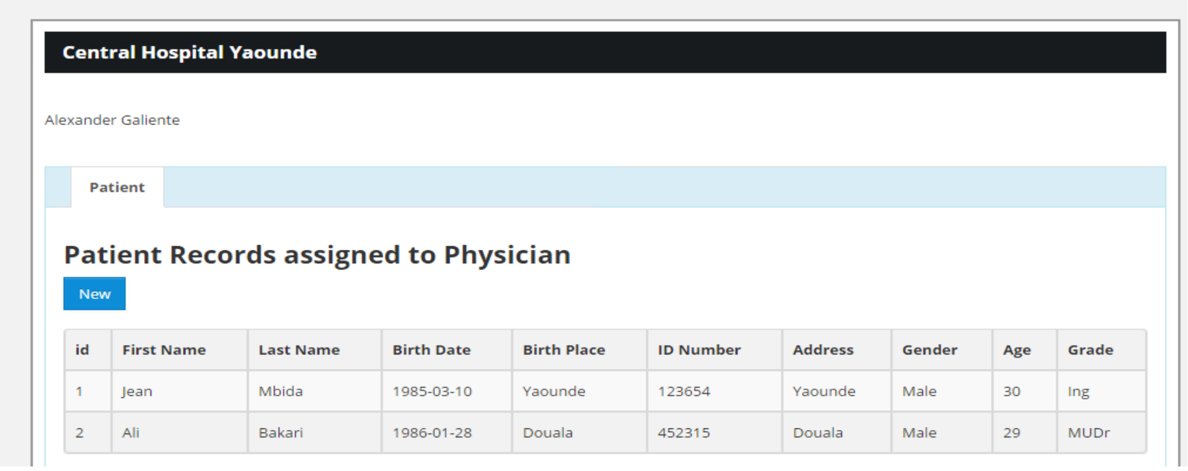
Showing 1 to 4 of 4 entries

Figure 8.3: Resource Types created for the "*Central Hospital Yaoundé*" Organization.

Then a binding has been created between Patient and Diagnosis, and between Physician and Patient.

The following functionalities have been tested:

- Creating new records: new patients and physicians where created.
- Viewing records: the created patients/physicians could be viewed
- Editing a record: created patients/physicians were edited.
- Removing: some created patients/physicians were removed from the.
- Bindings: patients were assigned to physicians, and diagnoses were assigned to patients, (figures 8.4 and 8.5).



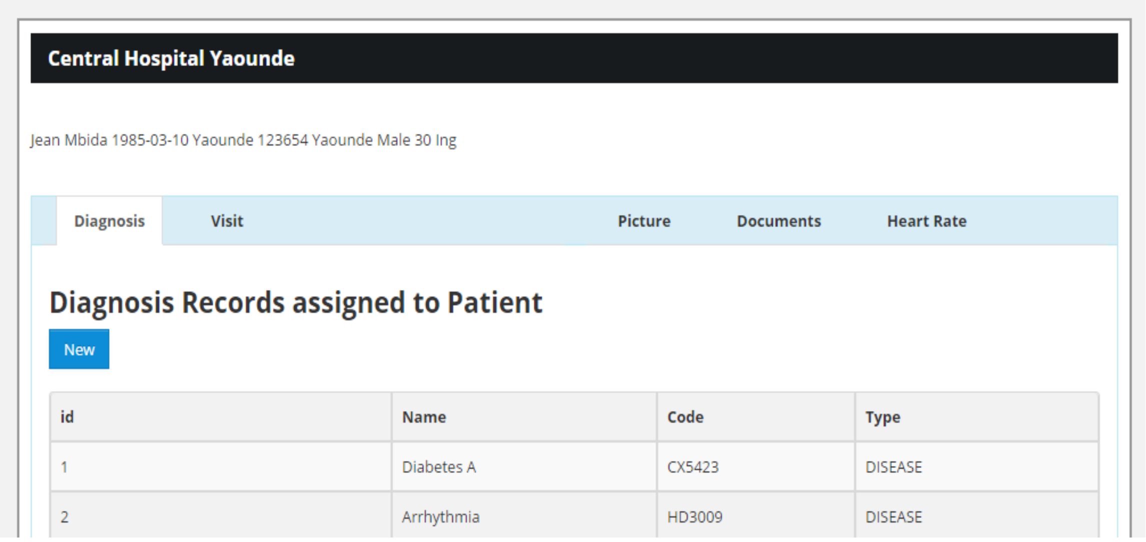
Central Hospital Yaounde

Alexander Galiente

Patient Records assigned to Physician

id	First Name	Last Name	Birth Date	Birth Place	ID Number	Address	Gender	Age	Grade
1	Jean	Mbida	1985-03-10	Yaounde	123654	Yaounde	Male	30	Ing
2	Ali	Bakari	1986-01-28	Douala	452315	Douala	Male	29	MUDr

Figure 8.4: Patients assigned to a Physician



Central Hospital Yaounde

Jean Mbida 1985-03-10 Yaounde 123654 Yaounde Male 30 Ing

Diagnosis Records assigned to Patient

id	Name	Code	Type
1	Diabetes A	CX5423	DISEASE
2	Arrhythmia	HD3009	DISEASE

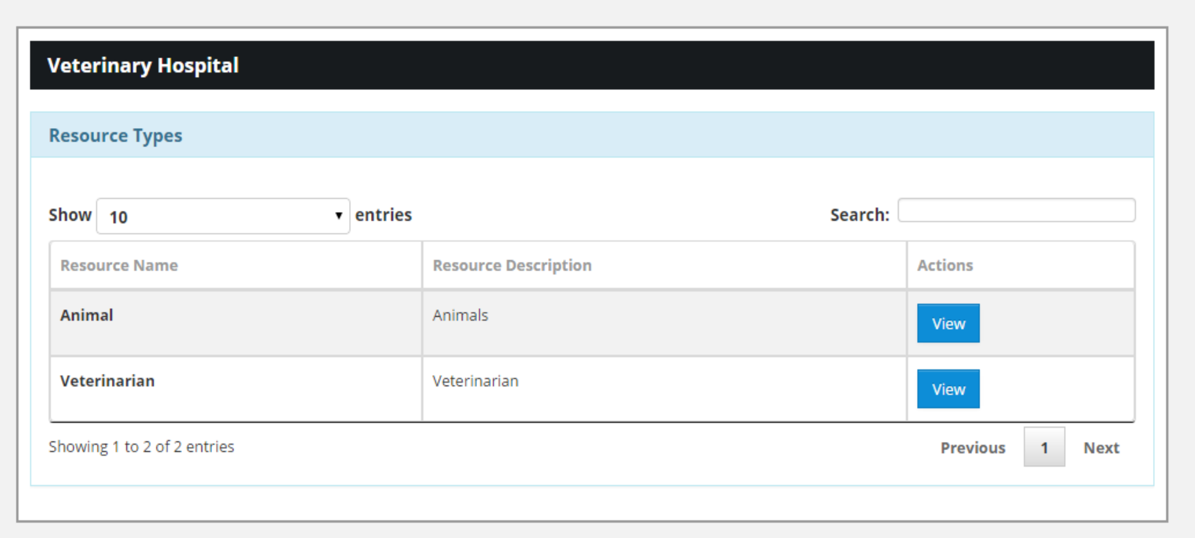
Figure 8.4: Diagnoses assigned to a patient

Third Organization: For the Veterinary Hospital, the following Resource Types were created:

- Veterinarian, with the following attributes: ID, First Name, and Last Name.
- Animal: ID, Name, Birth Date, Race, Gender.

Then a binding has been created between Veterinarian and Animal, where Veterinarian has been set as the parent Resource Type.

In figure 8.5 we ca view the result.

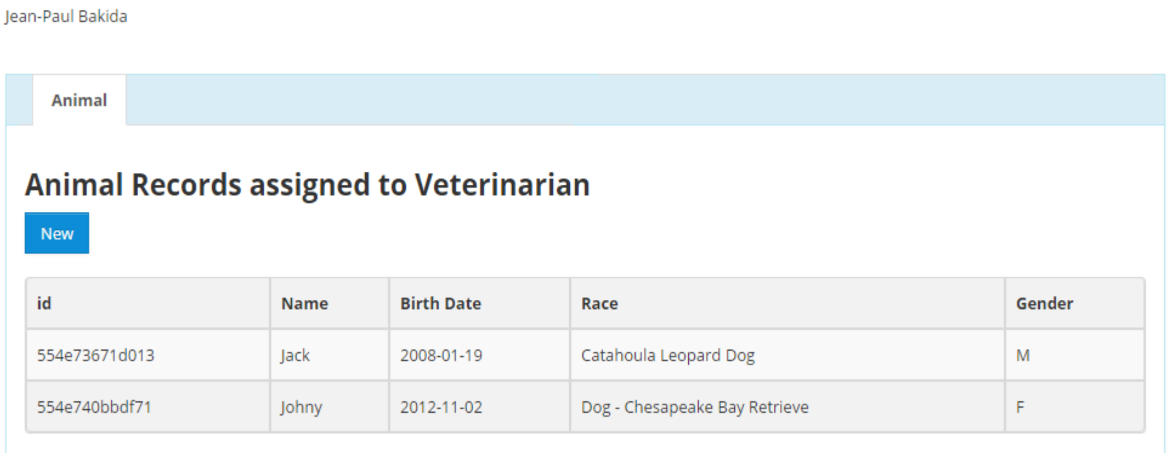


Resource Name	Resource Description	Actions
Animal	Animals	View
Veterinarian	Veterinarian	View

Figure 8.5: Testing Resource Types for the "*Veterinary Hospital*" Organization

The following functionalities have been tested:

- Creating new records: new animal patients and veterinarians where created.
- Viewing records: the created animal patient/veterinarians could be viewed
- Editing a record: created animal patients/veterinarians were edited.
- Removing: some created animal patients / veterinarians were removed from the.
- Bindings: animal patients were assigned to veterinarian (figure 8.6).



id	Name	Birth Date	Race	Gender
554e73671d013	Jack	2008-01-19	Catahoula Leopard Dog	M
554e740bbdf71	Johny	2012-11-02	Dog - Chesapeake Bay Retrieve	F

Figure 8.6: Resources of type Animal assigned to a Veterinary

Results: Three different business cases were created, with different needs. The first case can be adapted to a physician or doctor who would like to manage its patients and their visits. The second case can be used by a clinic for example, having more physicians, patients, with patients having their diagnoses saved in the system. Finally the last case illustrates that the system can be used also as a Veterinary center.

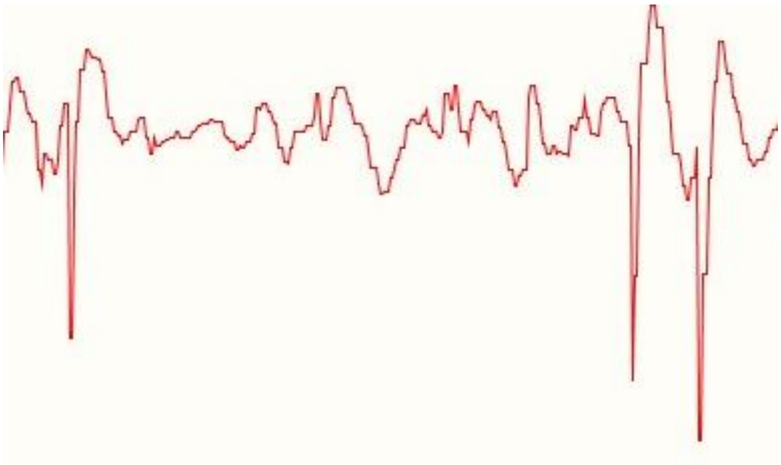
Different Resource Types with different attributes where created, and the system was manage them. All tested functionalities worked successfully.

8.2 Testing Heart Rate Measurement

The hardware prototype was tested by four users independently. Each of them has measured its heart rate and sent it successfully to the server using the implemented client application.

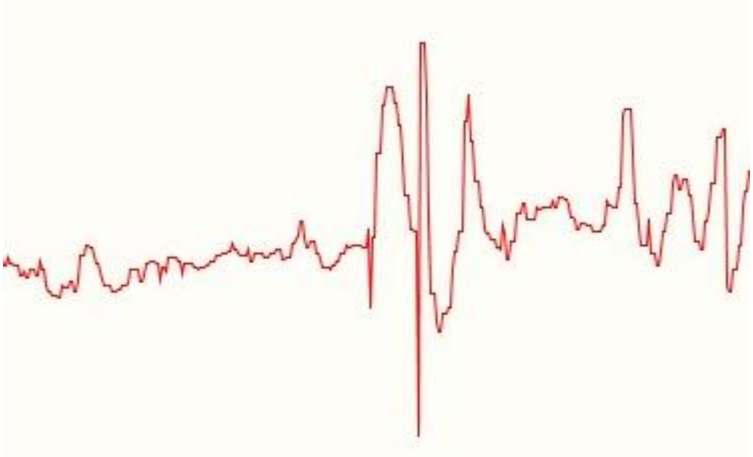
The experiments have been made in three different scenarios:

1) We tried to measure with the sensor not attached in the body at all: the result is shown in figure 8.7



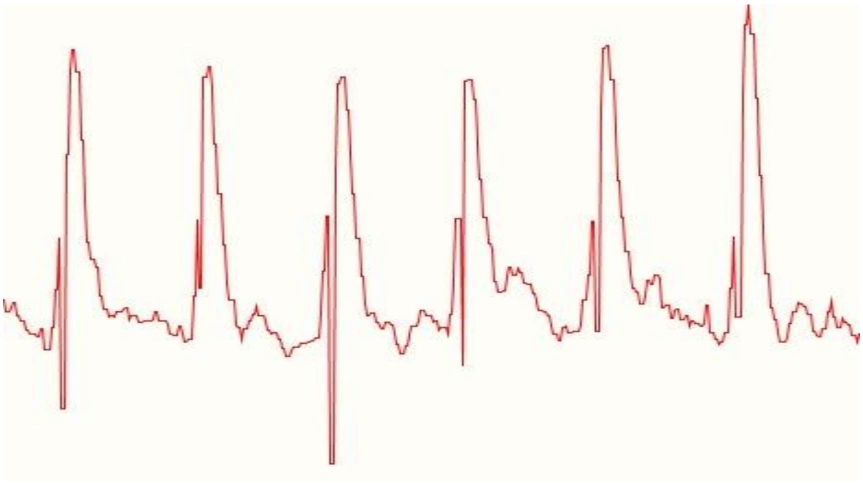
8.7 Example of measured signal, when the sensor is not attached on body

2) The sensor attached on ear lobe



8.8 Sensor attached on ear lobe

3) The sensor placed on finger



8.9 Sensor placed on finger

Conclusion:

When attached on finger, the sensor measured real hear rate.

Chapter 9

Conclusion

The aim of this thesis was to develop a web-based system allowing the patient data acquisition, storage and retrieving in low-resource environments. Before designing and implementing the system, we have first analyzed the requirements in telemedicine, especially in low-cost environments. This analysis consisted in communicating directly with potential users – patients and heath care specialists from different countries. This was done by means of a survey and also by personal contact with some doctors. We have also explored the literature to get more information about the requirements. All this analysis, including the study of existing open source solutions, allowed us to define our system requirements.

After defining the requirements, we proposed a solution that will meet these requirements. The proposed solution consisted in a client-server web application allowing patients to send data to their doctors or clinicians. The server part of the system is designed to be a dynamic system, allowing different organizations to customize it to their needs. Building such a system was not easy. It was time demanding and required deep analysis.

The results

The following was accomplished within this work:

- A prototype server application was implemented with basic functionalities, including the ability to dynamically create and manage resources, create and manage users, receive data from different client applications; store, retrieve and display the received data. The server can receive different types of data, including physiological data such as heart rate, or ECG signals.
- A client application has been created to allow sending data to the server.
- A prototype low-cost hardware solution was implemented to measure patient heart rate using a pulse sensor and a microcontroller. The measured samples can be saved into a file and sent to the server using the client application.

Further work

Even though the implemented system fits the requirements, many features remain to be implemented in order for the system to be more robust.

For example, different algorithms can be implemented for processing patient's physiological data. Different sheets and charts can be proposed for viewing resource data.

It would also be interesting to reconsider the data model. In our solution we are using a relational database. But other databases can be considered, such as NoSQL databases, which are built to allow the insertion of data without a predefined schema.

Another point that can be worked out as well is the implementation of a robust method for ensuring data integrity. Such method will allow the server to make sure that the data transmitted were not modified. This can be done using for example an advanced encrypting algorithm that would be implemented both in clients and server’s side.

This work did not include a comparative study of existing Open Source Software (OSS) and proprietary software in telemedicine. Even though we mentioned the existing OSS, we did not compare them between them. End-costs analysis for each OSS is missing as well (how product A is compared to B). We did not conduct a comparative study of PHP frameworks for the implementation of the system. We used CakePHP, but another framework could maybe meet better our requirements defined in chapter 2.

In this work we did not mention the standard HL7 format, which is widely used for data communication in medicine. HL7 messages could be sent and decoded using JSON format used for communication between clients and server. It would be also interesting to create in the server an interface for communication with RTG/MRI devices and other software such as OpenEMR.

When receiving data from the clients, the server does not provide a possibility to append data to previously added data.   This feature could be added as well.

In chapter 5 we mentioned naming conventions when it comes to naming the dynamically created Resource Types. Our solution works only for English names. It would be great to add UTF8 support and the use of ID instead of resource name for unique identification.

And finally a glossary is missing in this work. Some terms used here may be new for some readers.

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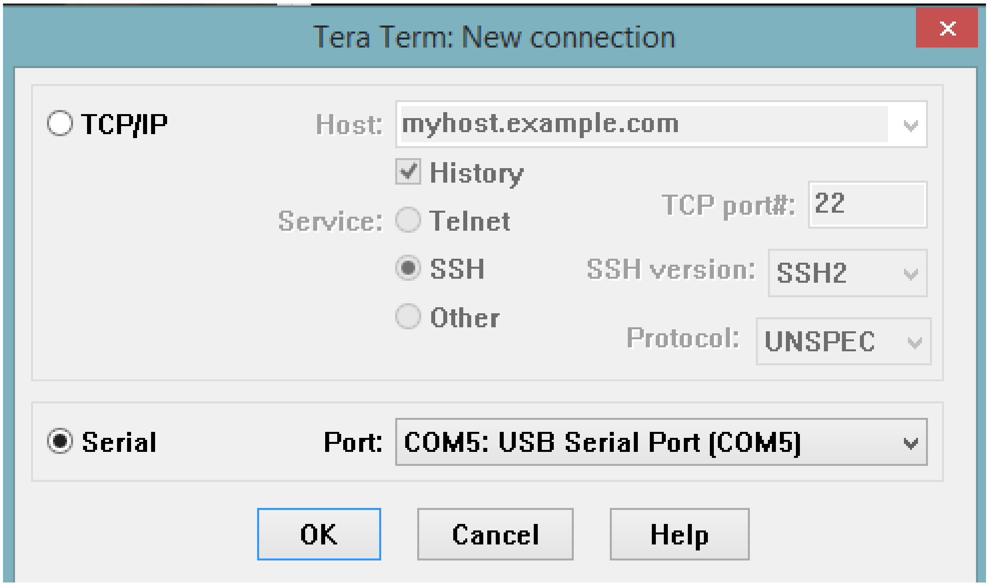
Appendix A User Manual for Measuring and Sending Data to the Server

To measure your heart rate, you are supposed to have, the Pulse Sensor, the board and a A-B USB cable. As serial client we are using Tera Term, but you may use another one, the process is the same.

1. Connect your Arduino or other board that you using to your PC using the A-B USB cable.
2. Place the Pulse Sensor on your finger
3. Open Tera Term and choose Serial



Tera Term: New connection

○ TCP/IP Host: myhost.example.com

☑ History

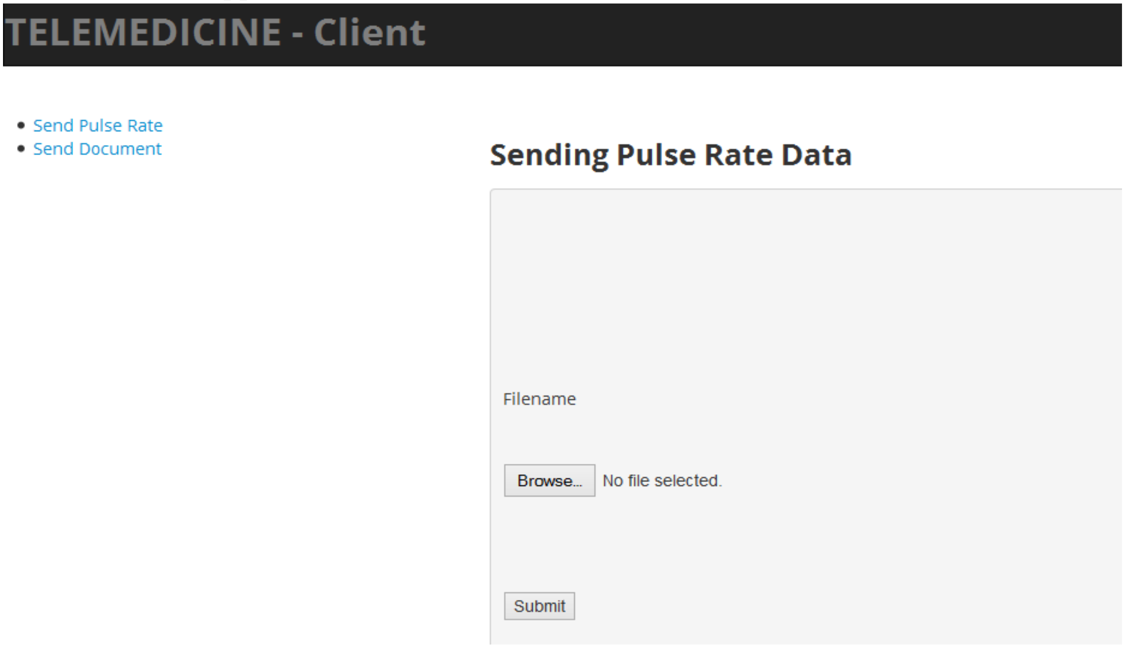
Service: ○ Telnet TCP port#: 22

● SSH SSH version: SSH2

○ Other Protocol: UNSPEC

● Serial Port: COM5: USB Serial Port (COM5)

4. Go to File and then choose Log and select a file where you would like to save you hear rate data
5. At this point you should see the measured values in the scree
6. When you think you are finish, simply close the terminal, data are saved in the file
7. Go to the client application and choose Send Pulse Rate



TELEMEDICINE - Client

- Send Pulse Rate
- Send Document

Sending Pulse Rate Data

Filename

Browse... No file selected.

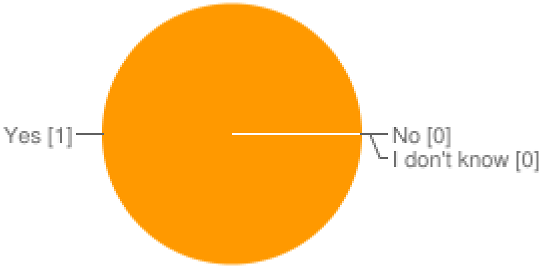
8. Click to Click to Browse and select your pulse rate file and click to submit.

Appendix B Survey

In order to have an idea of user requirements, we have realized a survey, using Google Form. The survey was realized in English and in French. Answers given in French are described in chapter 2. Among the participants, two were doctors. All are men from Congo, Cameroun, France, Czech Republic and Switzerland. The questions and the result of the survey are summarized below.

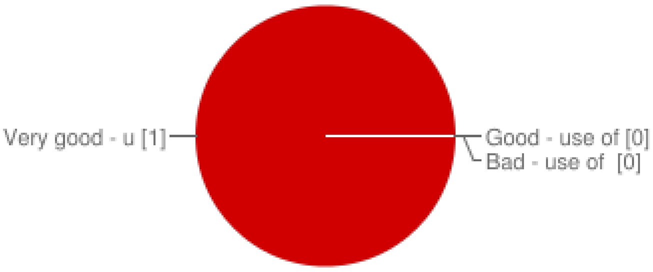
Telemedicine in your country/region

1. Is there Telemedicine use in your country?



Yes	1	8.3 %
No	0	0 %
I don't know	0	0 %

2. How would you rate the use of Telemedicine ?



Very good - use of Telemedicine is necessary	1	8.3 %

Good - use of Telemedicine is good but not really necessary	0	0 %
Bad - use of Telemedicine is not good	0	0 %

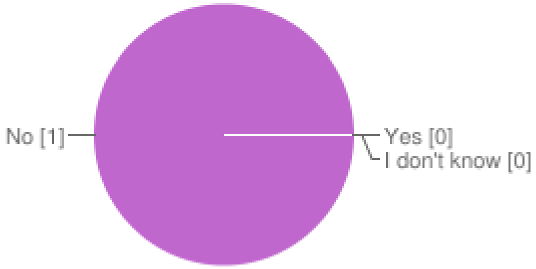
3. What are the main difficulties you encounter while using Telemedicine?

Telemedicine software programs are not free or not available	1	100 %
Telemedicine software programs are difficult to understand	1	100 %
Telemedicine software programs don't offer the needed functionalities	1	100 %
Lack of infrastructure	1	100 %
Problems with Internet connection	1	100 %
Ostatní	0	0 %

4. Can you tell which is roughly the percentage of people who use Telemedicine in your region / country?

Less then 10%	1	8.3 %
More then 10%	0	0 %
Between 10 and 50 %	0	0 %
More then 50%	0	0 %
I don't know	0	0 %
Ostatní	0	0 %

5. Is there use of Telemedicine in form of free software?



Yes	0	0 %
No	1	8.3 %
I don't know	0	0 %

6. If so, can you tell us what is (are) the open-source program(s) used for this purpose?

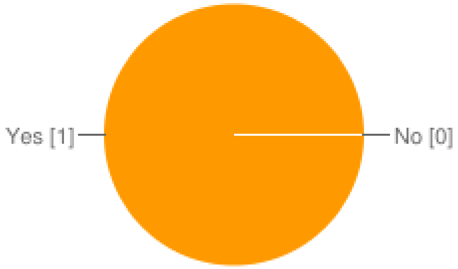
7. What are the benefits?

Connecting patients and doctors	1	100 %
Making remote diagnosis	1	100 %
Sharing data	1	100 %
Ostatní	0	0 %

8. how to improve it? (what would be good to do)

Use of Telemedicine

9. Are you interested in connecting with your doctor/patients remotely?



Yes	1	8.3 %

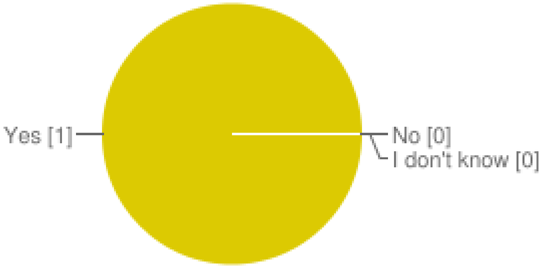
No	0	0 %

10. How do you imagine such a scenario?

11. Which kind of data would you share ?

Text	1	100 %
Images	1	100 %
videos	1	100 %
ECG signals	1	100 %
Ostatní	0	0 %

12. Do you have medical devices for data collection in a mobile environment?



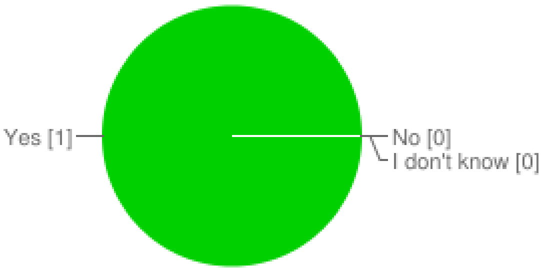
Yes	1	8.3 %
No	0	0 %
I don't know	0	0 %

13. If not which kind of device could you imagine to require?

14. Do you see any benefits in such a solution?

Legistation

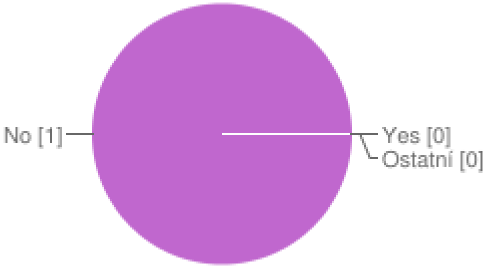
15. Is Telemedicine legal in your country?



Yes	1	8.3 %
No	0	0 %
I don't know	0	0 %

16. Which certifications are required by the local government in order to use a health care software?

17. Is there a legal framework for remote consultancy, diagnosis and prescriptions?



Yes	0	0 %
No	1	8.3 %
Ostatní	0	0 %

18. What does the local legislative say about patient data security?

Which features would you welcome in Telemedicine use?

19. Select features you would like to have in Telemedicine sofware

Remote connection between patients and doctors	1	100 %
Tools allowing sharing data such as images, text, ECG signals...	1	100 %

Evaluation of autonomic cardiac tests	1	100 %
Upload of the ECG signals	1	100 %
Social networking or other conversation tools	1	100 %
Patient management	0	0 %
Patient Scheduling	0	0 %
Electronic Medical Records	0	0 %
Online prescriptions	0	0 %
Multilanguage Support	0	0 %

Can you tell us something about yourself?

20. What is your nationality?

Cameroonian

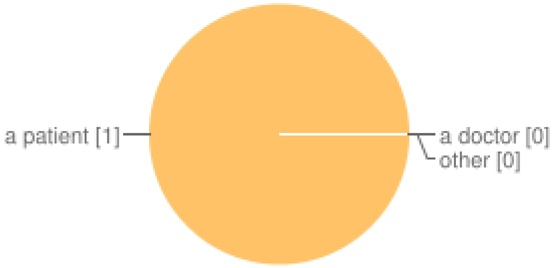
21. In which City / region do you live?

Prague

22. What is your country of origin?

Czech Republic

23. You are expressing yourself here as



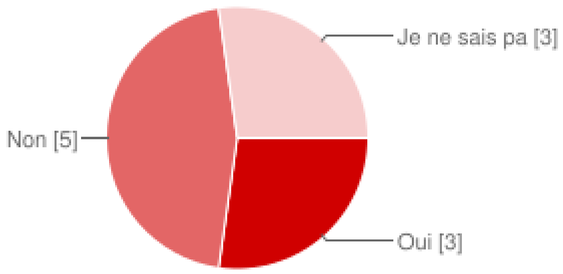
a doctor	0	0 %
a patient	1	8.3 %
other	0	0 %

24. Your name

25. Your email address

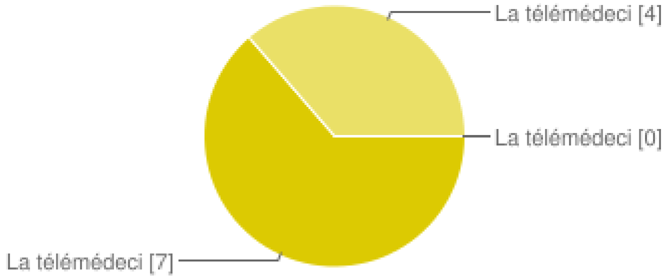
La télémédecine dans votre pays / région

1. La télémédecine est-elle utilisée dans votre pays ?



Oui	3	25 %
Non	5	41.7 %
Je ne sais pas	3	25 %

2. Que pensez-vous de l'utilisation de la télémédecine ?



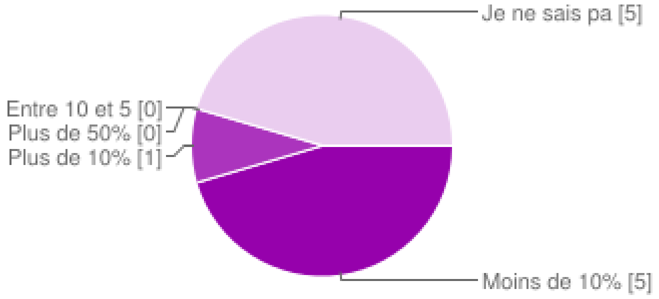
La télémédecine est nécessaire	7	58.3 %
La télémédecine est utile, mais ce n'est vraiment pas une nécessité	4	33.3 %
La télémédecine n'est vraiment pas utile	0	0 %

3. Quelles sont les principales difficultés que vous rencontrez lors de l'utilisation de la télémédecine ?

Il n'y a pas de logiciel de télémédecine qui soit libre ou gratuit	5	45. 5 %

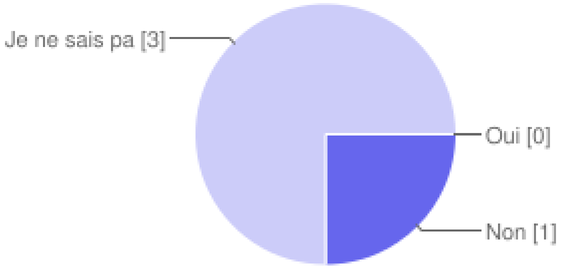
Les logiciels de télémédecine existants sont difficiles à comprendre	2	18.2 %
Les logiciels de télémédecine existants n'offrent pas les fonctionnalités nécessaires	2	18.2 %
Le manque d'infrastructure	7	63.6 %
Des problème liés à la connexion Internet	6	54.5 %

4. Pouvez-vous dire quel est à peu près le pourcentage de personnes qui utilisent la télémédecine dans votre pays / région ?



Moins de 10%	5	41.7 %
Plus de 10%	1	8.3 %
Entre 10 et 50%	0	0 %
Plus de 50%	0	0 %
Je ne sais pas	5	41.7 %

5. La télémédecine est-elle utilisée sous forme de logiciel libre dans votre pays / région ?



Oui	0	0 %
Non	1	8.3 %
Je ne sais pas	3	25 %

6. Si oui, quels sont les logiciels utilisés ?

en passant je souhaite ajouté que les NTIC vienne de voir le jour en afrique plus présicement au congo par exemple, certaine structure medical manque encore des outils telque un simple ordinateur, aller comprendre l'innovation c'est bien mais préparer les gens avant celle-ci c'est mieux c'est ce qui manque en afrique plus précisement au congo.

7. Quels sont les avantages liés à ces logiciels ?

La connexion à distance entre patients et docteurs	6	66.7 %
La possibilité d'établir un diagnostic en ligne	4	44.4 %
Le partage des données médicales	4	44.4 %
Autres	4	44.4 %

8. Y a t-il des améliorations que l'on peut faire sur ces logiciel d'après vous ?

Je pense seulement des fonctions liées avec le coeur. On peux aussi penser d'epilepsie, diabète, dialyse, etc.

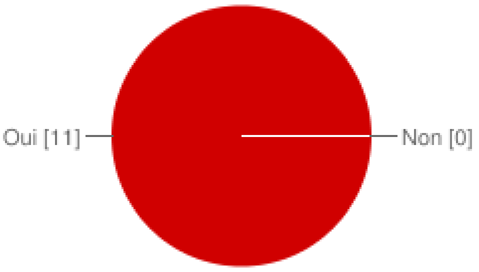
Certaines de tes questions s'adressent plutôt a des professionnels de santé !! Il est difficile d'y répondre ..... pourquoi n'aurais-tu pas fait 2 questionnaires : 1 pour les "patients" et un autre pour le "corps médical" Une info importante pour toi : il y a quelques jours la justice française a autorisé les pharmaciens à vendre certains médicaments (500 je crois) par Internet. Il faudrait que tu consultes la presse française pour avoir plus de précisions...

oui beaucoup même !! mais tout dependras du secteur d'utilisation !!

Dans mon Pays, la télémedécine ne se fait pas. il n'y a pas même un projet dans ce genre

L'usage de la télémédecine

9. Pensez-vous qu'il soit utile de permettre la connexion à distance entre les patients et les médecins ?



Oui	11	91.7 %
Non	0	0 %

10. Comment imaginez-vous ce scénario ?

Permetre une connection amelioré a internet et un acces pour tous. Creer des formations pour des specialists

En Suisse, les pharmacies ont établi un système de télémédecine qui permet au patients qui n'arrivent pas à obtenir un rendez-vous chez leur médecin de famille et qui n'estiment pas nécessaire d'aller aux urgences de se mettre en communication avec un médecin en ligne, en présence d'un pharmacien. L'utilité de ce système est mis en question parce qu'on soupçonne les pharmaciens de vouloir vendre avant tout des médicaments....

il faut déjà commencer par mettre en place les structures necessaires pour permettre sa pratique. ensuite s'assurer que la connexion internet soit de bonne qualité (capacité)

la encore c'est un problème suite au fait que beaucoup ingnore encore bien l'utilisation des outils informatiques et autres

Dans les zones rurales pour des RDV de routine, par exemple pour des personnes âgées ne necessitant pas la présence du médecin ou très éloigné. Cela peut aussi être le cas pour le suivi de la médication.

Par email interposé peut-être ; mais comment serait facturée et payée la "consultation virtuelle" ???

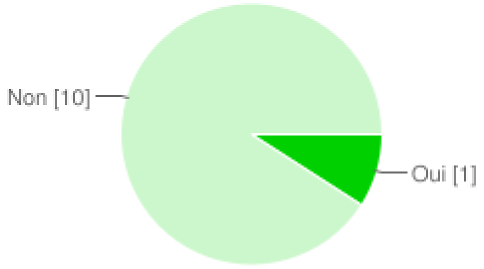
Les personnes malades (v.s.) ou agées peuvent être liées avec leur médecin qui fait la supervision ou par ligne de telephone ou mieux par Internet.

Une connexion à distance via une visioconférence faisant intervenir les médecin d'où qu'il se trouve pour soigner les malades.

11. Quel genre de données aimeriez-vous partager ?

Les textes	10	90.9 %
Les images	9	81.8 %
Les vidéos	9	81.8 %
Les signaux cardiaques	8	72.7 %

12. Avez-vous des dispositifs médicaux nécessaires pour collecter les données dans un environnement mobile ?



Oui	1	8.3 %
Non	10	83.3 %

13. Si non, quel type de dispositif pensez-vous qu'il serait bien d'utiliser ?

Question pour les "professionnels de santé"

Le petit appareil de ECG ou q.c. similaire.

N'étant pas du domaine médical, je suis incapable de vous donner les dispositifs médicaux indispensables dans un environnement mobile.

14. Pensez-vous qu' une telle solution serait avantageuse ?

Pourkoi pô.....?!:/;?:/.

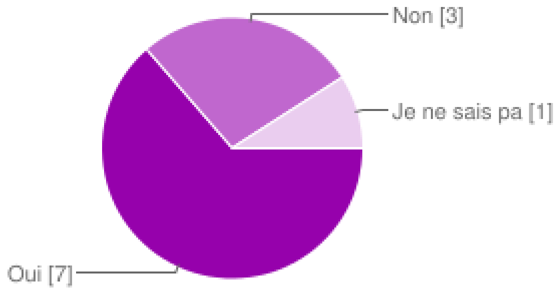
Oui, en cas de danger d'infarctus ou de la faiblaisse ou une crise de diabète etc.

Je pense que oui.

oui

Législation

15. La télémédecine est-elle légale dans votre pays ?



Oui	7	58.3 %

Non	3	25 %
Je ne sais pas	1	8.3 %

16. Quelle sont les démarches légales à faire afin de pouvoir être en droit de faire usage de la télémédecine ?

je crois que pour ce qui est des NTIC il faut passer par ARPCE au congo bien sûr je pense !!

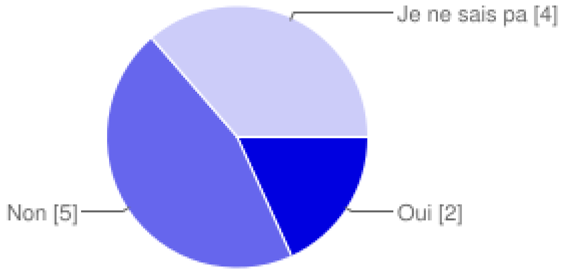
Je ne sais pas.

Pas très informé sur le sujet.

Je pense, de mon expérience, que c'est ne pas le demarche légale mais plutôt le demarche dans le domaine de la médicine privé, c'est-à-dire c'est économie.

En France, il faudrait une loi votée par le parlement (assemblée nationale) et le sénat. Mais celà n'arrivera pas !! la seule possibilité d'utilisation de la "télémédecine" peut se faire entre professionnels de santé, c'est tout notamment pour échanger des documents radios et autres

17. Existe t-il une plateforme légale permettant les diagnostics, les consultations et les prescriptions à distance ?



Oui	2	16.7 %
Non	5	41.7 %
Je ne sais pas	4	33.3 %

18. Que dit la législation locale sur la sécurité des données des patients ?

Secret médical de toutes façons !!!!!

Qu'elles doivent être protégées. Souvent il y a un conflit d'intéret, en Suisse, les assurances maladadie offrent des service de télémédecine (par téléphone), mais ils doivent traiter les données avec confidentialité (ce qui n'est pas tj respecté)

L'état tchèque a la legislation d'UE qui tient sur la sécurité des données des patients.

Pas très informé sur le sujet.

Quelles fonctionnalités aimeriez-vous avoir dans le cadre de l'utilisation de la télémédecine ?

19. Veuillez choisir les fonctionnalités que vous jugez utiles dans une plateforme télémédecine

La connexion à distance entre patients et médecins	10	90.9 %
Les outils permettant le partage des données telles que des images, du texte, des signaux ECG	10	90.9 %
L'évaluation des tests cardiaques autonomes	4	36.4 %
La mise en ligne des signaux ECG	6	54.5 %
Les réseaux sociaux ou autres outils de conversation	5	45.5 %
La gestion des patients	5	45.5 %
La planification des visites avec les patients	10	90.9 %
La gestion des dossiers médicaux électroniques	7	63.6 %
Les prescriptions en ligne	9	81.8 %
Le support de plusieurs langues	7	63.6

%

Renseignements sur vous

20. Votre nationalité

Congolaise

congolaise

CONGO/FRANCE

Tchèque

Camerounaise

Française

Suisse

Congo

21. Dans quel pays ou région vivez-vous actuellement ?

France

FRANCE

R. Tcheque

Europe

CANNES (France)

afrique centrale

congo

République Tchèque

Tchèquie, Prague

Suisse

22. Quel est votre pays d'origine ?

France

CONGO

congo

République du congo

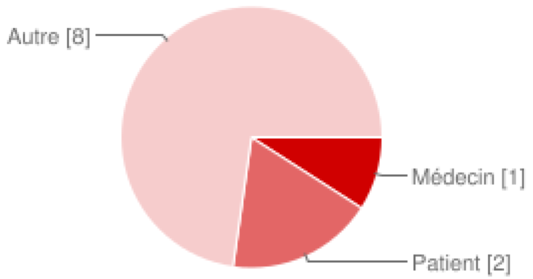
Tchèquie, Prague

Cameroun

Suisse

Congo

23. Vous vous exprimez ici en tant que ...



Médecin	1	8.3 %
Patient	2	16.7 %
Autre	8	66.7 %

Appendix C Contents of the attached CD

A CD with source codes and other materials is attached to the thesis.

The content of the CD is organized in following directories:

- Text/: contains electronic version of the thesis text.
- Code/server: the implementation of the server.
- Code/client: the implementation of the client.
- Code/Arduino: the implementation of the heart pulse in Arduino.