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Employment of Artificial Intelligence Mechanisms for e-Health Systems in Order to Obtain Vital Signs and Detect Diseases from Medical Images Improving the Processes of Online Consultations and Diagnosis

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Master in Computer Science

Supervisor:
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TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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“I love those who can smile in trouble, who can gather strength from distress, and grow brave by reflection. 'Tis the business of little minds to shrink, but they whose heart is firm, and whose conscience approves their conduct, will pursue their principles unto death.”

Leonardo da Vinci.

Acknowledgments

I would like to express my appreciation to my father, for his dedication and help during my difficult times. Also, my love to my mother that I will never forget.

Gratitude to all my previous jobs around many countries that taught me how to develop applications in a professional manner and to my colleagues, which gave important feedbacks and insights allowing me to see the correct path.

My greetings to the professor Carlos Coutinho for giving me all the support and necessary guidance.

Thanks ISCTE for giving me the chance to develop my skills and also for everything I have learned in so many areas during this course of computer science providing me the knowledge to implement full informatics engineering projects.

During this master I have been through marvelous experiences, met amazing people and developed so many softwares for so many curricular units, learning new programming languages and insights that I might use in the future and also changed my way of addressing problems and how to find solutions. There were also hard times, discussions, nights without sleeping, intensive research and code testing allowing me to increase my capacity of taking other challenges. Many reunions and analyses were done and I will always remember the good moments in my heart.

This course of computer science allowed me to develop my skills in game development, animation and 3D programming among other areas, providing new insights and processes that will help my future projects.

With the help of my several teachers and family I was able to discover a more humanitarian side of my personality and in loving memory to my mother, I would like to mention that this dissertation is just a study in order to inspire the passion for science to others and to increase the possibility of improving primary care and showing strategies that might help in future to detect, prevent and provide the correct treatment for some diseases and also to start acting on secondary care with more specification to certain diseases using higher frequencies.

The best thing you can do in life is to help others, especially in sensitive cases, providing defenses to horrible things that may occur because we are all made of energy.

God Bless.

Resumo

No quotidiano, as aplicações Web e-Saúde permitem aos médicos acesso a diferentes tipos de funcionalidades, como saber qual a medicação que o doente consumiu ou a realização de consultas online.

Os sistemas via internet para a saúde podem ser melhorados, utilizando mecanismos de inteligência artificial para os processos de deteção de doenças e de obtenção de dados biológicos, permitindo que os médicos tenham informações importantes que facilitam o processo de diagnóstico ou a escolha do tratamento correto para um determinado utente.

O trabalho de investigação proposto pretende apresentar uma abordagem inovadora na comparação com as plataformas tradicionais, ao disponibilizar sinais vitais online em tempo real, acesso a um estetoscópio web, a um *uploader* de imagens médicas que prevê se uma determinada doença está presente, através de métodos de aprendizagem profunda, bem como permite visualizar todos os dados históricos de um paciente.

Esta dissertação visa defender o conceito de consultas virtuais, providenciando funcionalidades complementares aos processos tradicionais de realização de um diagnóstico médico, através da utilização de práticas de engenharia de software.

O processo de obtenção de sinais vitais foi feito através de inteligência artificial para visão computacional utilizando uma câmara de computador. Esta metodologia requer que o utilizador esteja em estado de repouso durante a obtenção dos dados medidos.

Esta investigação permitiu concluir que, no futuro, muitos processos médicos atuais provavelmente serão feitos online, sendo esta prática considerada extremamente útil na análise e tratamento de doenças contagiosas, ou de casos que requerem acompanhamento constante.

Palavras-chave: Visão Computacional, Inteligência Artificial, Cuidados de Saúde, Aprendizagem Profunda, Engenharia de Software e e-Saúde.

Abstract

Nowadays e-Health web applications allow doctors to access different types of features, such as knowing which medication the patient has consumed or performing online consultations.

Internet systems for healthcare can be improved by using artificial intelligence mechanisms for the process of detecting diseases and obtaining biological data, allowing medical professionals to have important information that facilitates the diagnosis process and the choice of the correct treatment for each particular person.

The proposed research work aims to present an innovative approach when compared to traditional platforms, by providing online vital signs in real time, access to a web stethoscope, to a medical image uploader that predicts if a certain disease is present, through deep learning methods, and also allows the visualization of all historical data of a patient.

This dissertation has the objective of defending the concept of online consultations, providing complementary functionalities to the traditional methods for performing medical diagnoses through the use of software engineering practices.

The process of obtaining vital signs was done via artificial intelligence using a computer camera as sensor. This methodology requires that the user is at a state of rest during the measurements.

This investigation led to the conclusion that, in the future, many medical processes will most likely be done online, where this practice is considered extremely helpful for the analysis and treatment of contagious diseases, or cases that require constant monitoring.

Keywords: Computer Vision, Artificial Intelligence, Healthcare, Deep Learning, Software Engineering and e-Health.

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Acronyms

ºC Celsius Degrees**.**

AI Artificial **I**ntelligence.

API Application **P**rogramming **I**nterface.

BI Business **I**ntelligence.

BPM Beatings **p**er **M**inute.

Ch channel.

CI Continuous **I**ntegration.

CNN Convolutional **N**eural **N**etwork.

CPU Central **P**rocessing **U**nit.

CT Computer **T**omography.

CRUD Create **R**ead **U**pdate and **D**elete.

CV Computer **V**ision.

DSR Design **S**cience **R**esearch.

ECG Ele**c**trocardio**g**ram.

FFT Fast **F**ourier **t**ransform.

FLIR Forward **L**ooking **I**nfra**r**ed.

GUI Graphical **U**ser **I**nterface.

HTML Hyper**t**ext **M**arkup **L**anguage.

HTTP Hyper **T**ext **T**ransfer **P**rotocol.

HTTPS Hyper **T**ext **T**ransfer **P**rotocol **S**ecure.

HZ Hert**z**.

ICA Independent components.

IDE Integrated **D**evelopment **E**nvironment.

IoT Internet **o**f **T**hings.

IS Information **S**ystem.

IP Internet **P**rotocol.

IR Infra**r**ed.

JADE Joint **A**pproximation **D**iagonalization of **E**igen-matrices.

JSON Java**S**cript **O**bject **N**otation.

LED Light-**e**mitting **D**iode.

mmHg Millimeter of **M**ercury.

MRI Magnetic **R**esonance **I**maging.

MVC Model **V**iew **C**ontroller.

PHP Hypertext Preprocessor.

PPG **P**hoto**pl**ethysmo**g**raphy.

RGB **R**ed, **G**reen and **B**lue.

ROI **R**egion **o**f **I**nterest.

ResNet **Res**idual neural **net**work.

REST **R**epresentational **S**tate **T**ransfer.

SLR **S**ystematic **L**iterature **R**eview.

SOA **S**ervice-**O**riented **A**rchitecture.

SOAP **S**imple **O**bject **A**ccess **P**rotocol.

SpO2 Oxygen saturation.

UDDI **U**niversal **D**escription, **D**iscovery, and **I**ntegration.

VGG **V**isual **G**eometry **G**roup.

WSDL **W**eb **S**ervices **D**escription **L**anguage.

XLR E**x**ternal **L**ine **R**eturn.

XML E**x**tensible **M**arkup **L**anguage.

XRD **X**-**r**ay **D**iffraction.

XRF **X**-**r**ay **F**luorescence.

1. Introduction

This study aims to research the problem of performing a correct medical diagnosis defending the concept of online consultations. Several strategies were followed like making available a web stethoscope, using deep learning to identify specific diseases in an uploaded medical image, or obtaining the vital signs using cameras from common devices like a computer or phone.

1.1 Context and Motivation

Over the last years, there were many improvements on the web technologies used for therapeutic and curative services; e-Health combines several fields like medical informatics, business and public health using the internet as an important aspect for performing important tasks [1].

The usage of online systems for healthcare has been increasing and can be helpful for handling contagious diseases or the treatment of chronic illness. This can contribute to a tendency to convert some hospital systems to remote ambulatory processes [2].

In order to understand the health status of the patient, artificial intelligence (AI) for computer vision (CV) can be used to know the vital signs like the oxygen saturation, blood pressure, systolic values, diastolic values, body temperature, cardiac frequency, and respiratory rate.

The interaction between physicians, patients and prescriptions can be done online, being less time-consuming, shortening distances, and allowing this interaction to be accessed in less developed regions, because health is important for every person [3]. Virtual consultations can save lives and obtaining vital signs can help on the triage problem, identifying if a certain case requires intensive medical care, monitoring the response of a patient to therapy, determining the relative status of vital organs such as the heart and the lungs, observing trends in the health status, establishing a baseline for future comparison, or helping to decide if an intervention is necessary [4].

The artificial intelligence research for healthcare has been increasing over the last years. Many studies have shown good results in the areas of disease detection and patient monitoring. Several processes are being used to increase the accuracy of predicting a pathology or determining the health condition of a person. The work done in radiology or general medicine can be aided with deep learning methodologies in terms of diagnosing and monitoring patients. Currently, in some cases, the analysis is done using X-ray diffraction (XRD) and X-ray scattering by identifying and quantifying crystalline phases in the structure of the sample or X-ray fluorescence (XRF) to determine the elemental composition of a material.

The treatment of medical images with artificial intelligence can be seen as a complementary tool to the current processes of detecting diseases [5] by segmenting and classifying X-rays or computer tomography (CT) scans or magnetic resonance imaging (MRI) scans.

Stethoscopes are very important tools to listen what is happening inside the body, helping the physician to analyze the state of the heart and the lungs [6]. Hence, this research advocates that a spectrogram of the audio signals appearing via web on the screen for the physician facilitates his remote work.

Online healthcare systems can be complemented with Artificial Intelligence mechanisms, facilitating the process of diagnosing diseases and determining the most appropriate medical treatment to apply.

1.2 Problem Definition

The current online consultations do not provide enough information [7]; therefore, displaying to the physician the vital signs [8] in real time via web, is expected to improve the diagnosis process, helping to identify possible diseases and determine their severity level. The traditional process requires too much work, has high costs, is very time consuming and is prone to human error. Although the current artificial intelligence mechanisms still have some limitations, their accuracy and performance can be increased at lower costs than the ones performed by a human in a laboratory [9]. Additionally, some diseases, like the viral ones, are difficult to diagnose, because of the time of development of the pathological agent [10].

Artificial intelligence offers an opportunity for improving online diagnosing systems avoiding human error such as the use of convolutional neural networks for CT scans, X-rays or MRI scans [11]. Current e-Health systems have high implementation and maintenance costs [16] and do not provide many functionalities, like classifying uploaded medical images or obtaining the vital signs.

New functionalities can be integrated to the online applications being used, providing other important functionalities that facilitate the work of the physician such as reading the vital signs via web.

1.3 Objectives

This research aims to offer an innovative solution for e-Health systems when compared to traditional processes, defending the theoretical concept of developing some medical activities online and increasing the performance of online consultations [17] and prescriptions, advocating that there is a need to improve the current medical systems [18] and methods.

This study took in consideration two possible diseases: covid-19 (from X-rays and CT scans of the thorax [13]) and brain tumors (from MRI scans of the brain [14]).

The proposed solution can be used as complementary to the current systems adding more functionalities to the web applications like reading the patient's vital signs.

Additionally, where medical images can be difficult to be analyzed by a human eye [12], this thesis proposes a web media uploader connected to an AI algorithm that can provide a prediction of the existence of a possible disease with a high level of accuracy, uploading medical images of the head and thorax to predict brain tumor or covid-19 [19].

Finally, checking the state of the lungs or the heart via a stethoscope just by human hearing [6] may induce to errors. The present study provides solutions like a "web stethoscope", which includes a spectrogram of the audio signals on a screen, which facilitates the work of the physician in analyzing these organs, making prescriptions and determining the severity of illnesses, and which can all be done remotely via web.

Some future extensions of the work that can be considered are the possibility of reaching less developed regions, reducing the risk of contagion for the physician, lower costs, takes less time and provides more mechanisms that can complement the existing ones.

The research aims to add a new methodology to the process of interaction between the physician and the patient [20]. The study focuses on the application of AI mechanisms on e-Health systems, complementing the current ones and facilitating the process of diagnosis and determining the severity of illnesses. The main objectives of the dissertation are to:

- Increase the accuracy of the readings of the vital signs obtained via a camera sensor (**#Objective_1**);
- Show the spectrogram of the sound signals of a stethoscope, so the physician can better identify the status of the organs heart and lungs (**#Objective_2**);
- Make a web application that stores the health status of the patient, based on the readings obtained, helping the physician to have historical data and analyze better the situation of a certain patient (**#Objective_3**);
- Investigate and create a methodology using datasets to determine if a certain X-ray or CT scan of the thorax has covid or a certain MRI scan from the brain has tumor using a convolutional neural network (CNN) composed by specific layers. (**#Objective_4**).

1.4 Research Questions

The investigation questions allow to determine the problem and fundament this paper, facilitating the achievement of the proposed objectives.

- How can the vital signs be obtained from a camera capturing the face of the user and the thumb? (**#Research_Question_1**);
- How can the sound signal obtained by a stethoscope that appears in a web spectrogram help the physician? (**#Research_Question_2**);
- How can an application store historical data of the previous obtained information such as body temperature, blood pressure (systolic and diastolic), cardiac frequency, oximetry, and respiratory rate? (**#Research_Question_3**);
- How can the disease covid-19 be detected in an X-Ray or CT scan of the thorax, and a brain tumor from an MRI scan of the brain using Deep Learning? (**#Research_Question_4**).

Answering the questions will allow achieving the proposed objectives. To achieve this goal, it was necessary to research the work of other authors, develop applications, and perform tests comparing the results obtained with medical devices.

The hypothesis considered for answering **#Research_Question_1** were manipulation of the average of the red, green and blue values of the images obtained by the camera via OpenCV to calculate the vital signs (**#Hypothesis_1**) or treatment of the plethysmography signal (**#Hypothesis_2**) and use of the green channel for heartbeat, breath rate and temperature detection and the red and blue channels for determining oximetry and blood pressure values (**#Hypothesis_3**).

Concerning **#Research_Question_2** the hypothesis considered was based in using a stethoscope with a microphone that connects to the computer showing the signal strength, or "loudness" of the signal over time (**#Hypothesis_4**).

For **#Research_Question_3** the hypothesis considered were the use of a three-tier architecture with a MySQL database and application programming interfaces (**#Hypothesis_5**) and use of Python to connect to a database storing the values of the artificial intelligence application (**#Hypothesis_6**).

The possibilities of answering **#Research_Question_4** were the use of a visual geometry group (VGG) model with 16 layers (**#Hypothesis_7**) or the use of another architecture like the residual neural network with 50 layers deep for the same datasets (**#Hypothesis_8**).

1.5 Research Methodologies

This section describes the main research processes used to elaborate this document, starting with the systematic literature review (SLR) and followed by the design science research (DSR).

1.5.1 Systematic Literature Review

A literature review methodology improves data treatment by identifying, analyzing, evaluating, and interpreting. The information obtained and the search was done taking in consideration specific concepts, the technologies that are going to be used, the previously defined research questions and keywords [21]. The 3 phases of Kitchenham [21] were performed: On phase 1 (Planning), a review protocol was implemented, and the objectives were defined. Concerning the selection criteria, this one was based on how the documents were relevant for the research questions. In phase 2 (Conducting), documents that were not relevant after reading the abstract, or that were duplicate or incomplete were removed from the initial dataset. Usage of the review protocol to find associations of the articles with the topics in cause and the technologies used, based on the relevance to the research questions. In phase 3 (Reporting the Review), several quality checks were performed on the existing data and filtered in order to be adequate and report efficiently mentioning the processes and conclusions obtained.

From an initial dataset of 114 studies obtained via database searching after using the review protocol, reading the abstract and filtering by taking in consideration criteria like relevance to the research questions, duplication and if the articles were incomplete, 80 articles were obtained and analyzed with more attention. Figure 1 shows the number of selected articles and the respective years of publication. The selected studies helped to understand how other authors approached the problem and what kind of processes are being used to achieve the objectives.

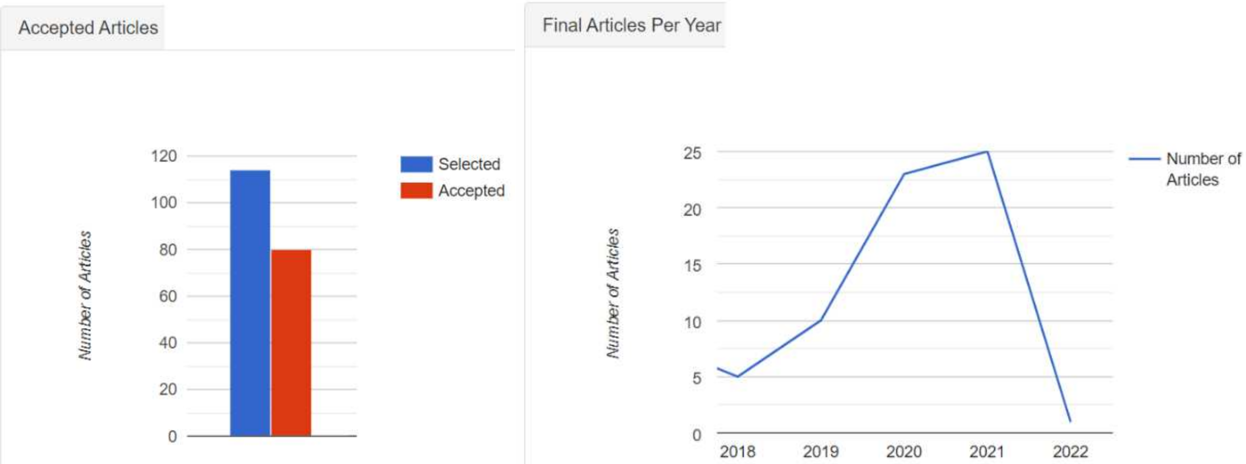


Figure 1. Selected studies and number of scientific articles analyzed per year.

1.5.2 Design Science Research

For this research study, the design science research methodology was used, which can be applied in information systems and has its origins in the engineering areas and artifact science, aiming to resolve problems via innovation, allowing to improve the current processes, ideas or products or create new ones in a more effective and efficient manner [22]. This work will use multiple iterations of the DSR because it will follow the continuous integration paradigm to try to find the technical feasibility problems and present a solution (see Figure 2).

Initially (first stage), the problem was defined, and subsequently (stage 2) the objectives were described for a possible solution. The third stage was based on developing the prototypes using several programming languages and platforms, and on the fourth stage the developed applications were used to try to solve the problem.

Concerning the evaluation (fifth) phase, several tests were performed, and the communication was done via this dissertation.

The chosen methodology for this paper was the design science research due to its common use in software engineering projects and also because it has an important iteration component, which is adjustable to the development practices.

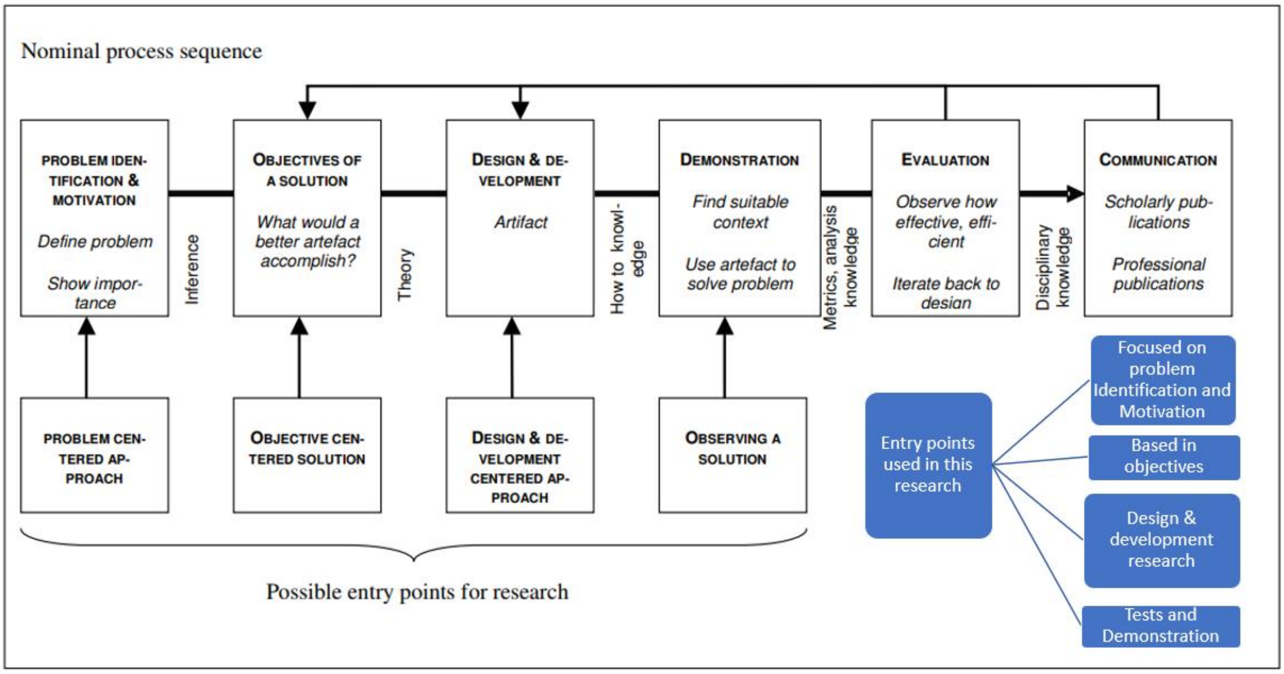


Figure 2. DSR model for this research, adapted from [24].

This research contributed to build a knowledge base composed by open-source code, web articles, fundaments and methodologies, which provided the raw materials through which the information system research is performed. Fundamental theories, structures, instruments, constructions, models, methods, and instantiations are used in the development phase. Methodologies provide guidelines used in the justify and evaluate phase. Rigor is achieved by properly applying existing foundations and methodologies. In behavioral science, methodologies are usually based on data collection and empirical analysis. In design science, computational and mathematical methods are used to assess the quality of the artifacts; however, empirical techniques can be used.

The work of Hevner [23] shows the guidelines of the design science research, the artifact presented is a set of applications and processes, these guidelines were applied in this dissertation as shown on Table 1 in order to achieve the proposed objectives.

Table 1. DSR adjusted to the project, adapted from [23].

Guideline	***Description***	***In Project***
Guideline 1:	Design as an artifact: The research performed has to provide a valid artifact that can have several representations.	System composed of several applications and processes allowing to obtain vital signs and classify X-rays, CT scans and MRI scans. Also, a spectrogram of the sound signal of a stethoscope was implemented and a video chat for consultations.
Guideline 2:	The relevance of the problem: The problem has to be clearly described and the importance should be proven.	Problem: The process of diagnosis requires too much work, takes too much time, is very expensive and human error should be avoided.
Guideline 3:	The evaluation of the project: Has to be rigorous and able to measure the quality and utility among other factors and metrics.	Evaluation processes: For the vital signs, tests were done and compared with the values of medical devices. For the X-ray, CT scan and MRI scan uploader the accuracy and loss will be calculated.
Guideline 4:	Research contribution: Should offer an improvement or a new tribute to the research area of the project.	• Add new functionalities to e-Health systems. • Improve the process of web consultations, diagnosis and prescriptions.
Guideline 5:	Research rigor: The evaluation and construct of the artifact should follow rigorous methods and procedures.	The rigorous methods are based on software engineering standards, improving the code and performing unit testing.
Guideline 6:	Design as a search process: The search for an effective artifact depends on using the means available to achieve the desired results.	A systematic literature review was used to obtain data to support the research. Many scientific articles were reed and also a deep search for existing code and programming processes.
Guideline 7:	Research communication: The demonstration of the work developed should be clear to all types of audiences.	The proof of concept of the proposed solution will be described in the dissertation and the applications are web based being available for different types of audiences.

1.6 Document Structure

This work is organized as follows: The current chapter 1 is where the context, motivation and definition of the problem is done, also mentioning the objectives, challenges and research questions which this dissertation intends to answer, followed by the research methodologies used. The second chapter mentions the theoretical background which provides concepts and principles to prove the nature of the problem, as well as related work and investigations showing how other authors approached the problem. Chapter three focuses on the proposed solution, which was separated (due to clinical reasons) in two sections, being the first related to analyzing the general state of health of the patient, offering a primary care approach, and the second more focused on organs and clinical specialties having a secondary care point of view.

The fourth chapter shows the several tests and results obtained taking in consideration qualitative and quantitative aspects, where the values of the vital signs obtained by the application are compared with the actual values of medical devices for the same testers at the same period of time. Concerning the tests for secondary care, the calculation of the accuracy and loss of the used deep learning model, based in the visual geometry group (a convolutional neural network that can classify images) with 16 layers architecture, was obtained for the gathered datasets. As a last step, a usability dataset was developed taking in consideration several variables allowing to obtain general patterns.

The final chapter shows the conclusions derived from all the developed process, taking in consideration the work performed and the results obtained mentioning the provided possible answers to the research questions and the strategy used to achieve the objectives as well as a description of future research.

2. Theoretical Background, Literature Review and Related Work

Taking in consideration the objectives, the proposed questions, the necessary technologies and the research performed by other authors, this section will provide more insights concerning the topics related with the investigation in cause, demonstrating the nature of the problems, how other researchers approached for a solution and which limitations and challenges exist. The chapter will mention the difficulties in adding functionalities to web e-Health systems and describe the work of other researchers in obtaining the vital signs via the photoplethysmography (PPG), as well as theoretical concepts of software engineering processes that allow to develop web applications and to perform services and operations online.

2.1 E-Health Applications

The e-health or “digital health” can be seen as a broad concept known worldwide that deals with digital tools and solutions that help improve the quality of life of the persons aiming to improve healthcare services; e-health include concepts like technology, commerce and health and takes in consideration place, distance and attitudes of the stakeholders [37]. The processes of diagnosis and consultation can be helped by e-health technologies, it is important that the physician gets all the important information in order to act accordingly and avoid cases of false positives and false negatives concerning disease detection. The use of video chats (see Figure 3) to perform consultations has been increasing and many technologies can be used to implement these types of systems like Java and NodeJS with the webRTC among other possibilities.

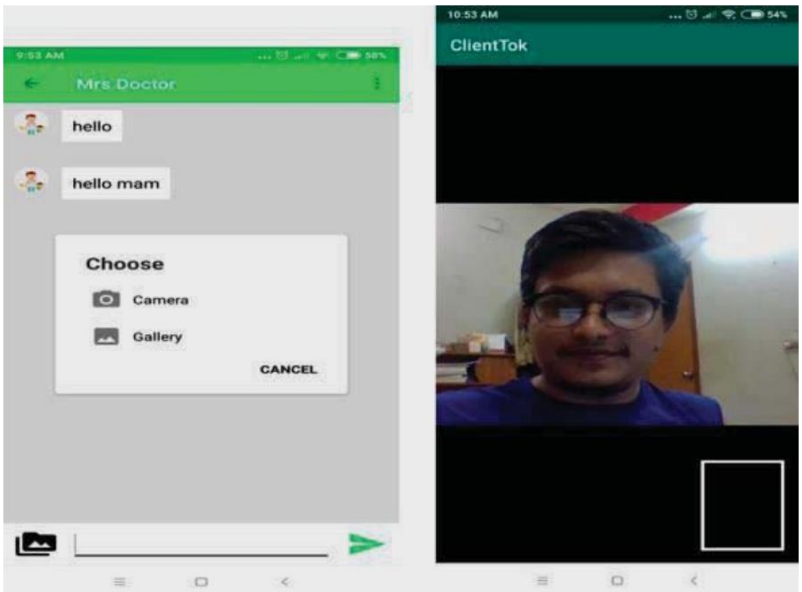


Figure 3. Video chat with the physicians [3].

Remote healthcare can save waiting time for the patients, avoid booking delays and can be accessed in less developed regions [3].

Via internet of things (IoT) is possible to integrate the information obtained by medical devices to a web application (see Figure 4).

Figure 4. Web interface for remote viewer and Vidavo e-health devices [65].

Nowadays e-health applications are being used for several purposes like providing the physician with information about the patient, such as which pills he acquired and consumed, which vaccines were taken, previous diseases and symptoms among other information, for some cases are used strategies of big data and cloud computing.

The e-health applications have some advantages like lower costs, physicians can access remotely, reduction of medical errors, improve the diagnosis process and some challenges in adding functionalities to web e-Health systems like difficulties in learning and using the software, standardizing all information systems and lack of qualified personnel. The use of electronic health records has some improvements like being available 24 hours a day and can help epidemiological research (Figure 5).

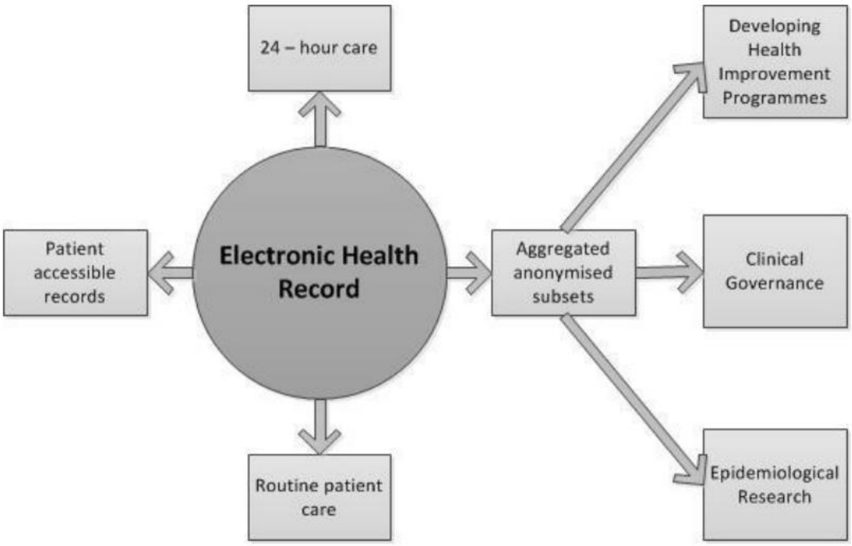


Figure 5. Uses of Electronic Health Records [38].

The e-health systems allow to ameliorate quality, efficiency, access and effectiveness of clinical and business activities utilized by healthcare organizations, physicians and consumers to improve the health status of patients [39].

2.2 Obtaining the Vital Signs

Several processes and devices can be used to obtain the vital signs, this section aims to show some of most common ones. This study took in consideration the analysis of cardiac frequency, respiratory rate, body temperature, blood pressure, systolic values, diastolic values and oxygen saturation.

Concerning cardiac frequency the objective is to know the number of heartbeats in one minute, the most common process is the use of the electrocardiography that generates an electrocardiogram (ECG, see Figure 6) which is a representation of the electrical signal and changes that occur during the cardiac cycle to check the health state of the heart, can be seen as a test that measures electrical activity of the heartbeat taking in consideration the electrical impulse of each beat [40].

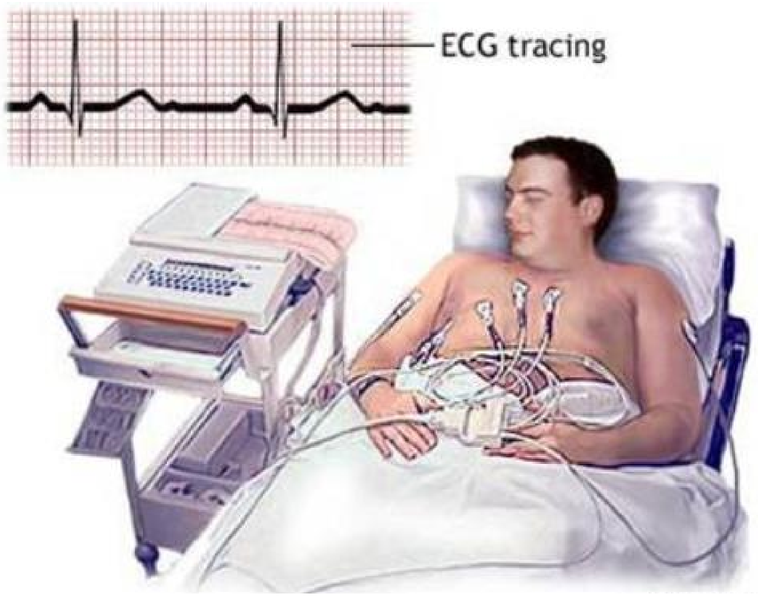


Figure 6. Making an electrocardiogram analysis [47].

The breathing rate per minute can be acquired by counting the number of exhales, for a more accurate result your body should be at rest as in example, it is better measured if you are in a sitting position or laid down in bed. Piezoelectric, plethysmography, capnography or bioimpedance-based sensors can read directly the number of respirations per minute.

Body temperature is usually measured via a thermometer but can also be measured by thermal cameras like the forward looking infrared (FLIR) that can detect differences in heat and senses infrared radiation (see Figure 7).

Figure 7. Flame and skin temperature measurement by FLIR thermal camera at pulse energy [61].

The measurement of blood pressure usually is done via a sphygmomanometer (Figure 8) composed by a cuff that squeezes the arm and also a mercury manometer that allows to measure pressure generally displayed in millimeters of mercury.

Figure 8. Different kinds of sphygmomanometers [50].

Some researchers followed a strategy of using the camera of the phone to obtain diastolic and systolic values (Figure 9) and for some cases the use of machine learning algorithms [52].

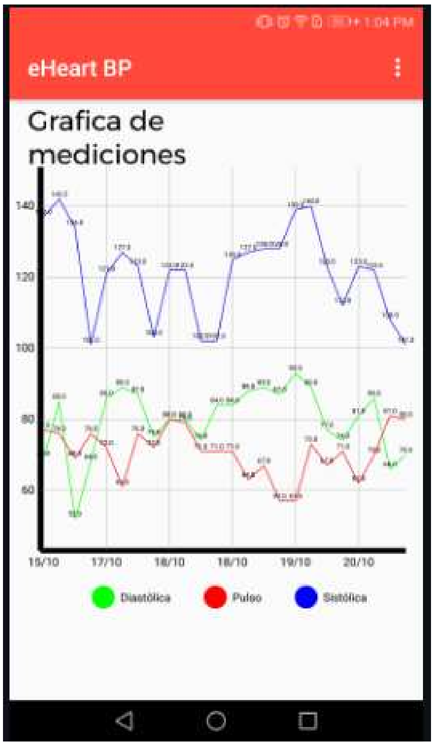


Figure 9. Plot with the readings of blood pressure [52].

In order to know how much oxygen is being carried in arteries or oxygen saturation (SpO2) normally is used an oximeter (Figure 10) that provides an estimation based on passing wavelengths of light through a part of the body usually the fingertip to a photodetector. This technique measures the absorption of the wavelengths for arterial blood only. Another possible test with more accuracy is the arterial blood gas analysis but is more expensive and the pulse oximetry is validated for clinical use.

Figure 10. Using an oximeter to obtain the SpO2 [62].

2.3 Treatment of the Photoplethysmographic Signal

Photoplethysmography is an optical technique to detect changes of the blood volume, giving important information about the cardiovascular system; The waveform (see Figure 11) has two parts, the alternating current (AC) and the direct current (DC). The AC component corresponds to the variations of the blood volume that are synchronized with the heart movements. The DC component is non pulsatile and based on the reflected optical signals and light absorption from the tissues depending on the tissue structure as well as venous and diastolic arterial blood volume [41].

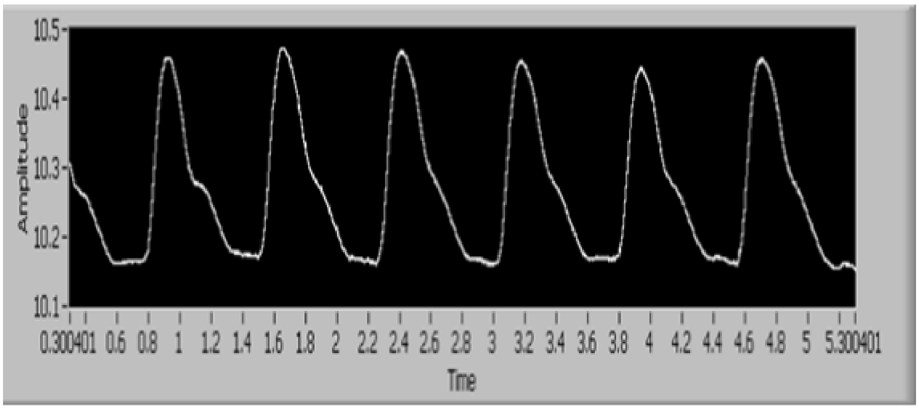


Figure 11. The PPG signal acquired in LabView [42].

To get the readings of some vital signals, a few devices like oximeters (usually have a red led) and smartwatches (normally use a green led) use this noninvasive technique that illuminates parts of the body and measures variations in the absorption of light using a photosensor (Figure 12).

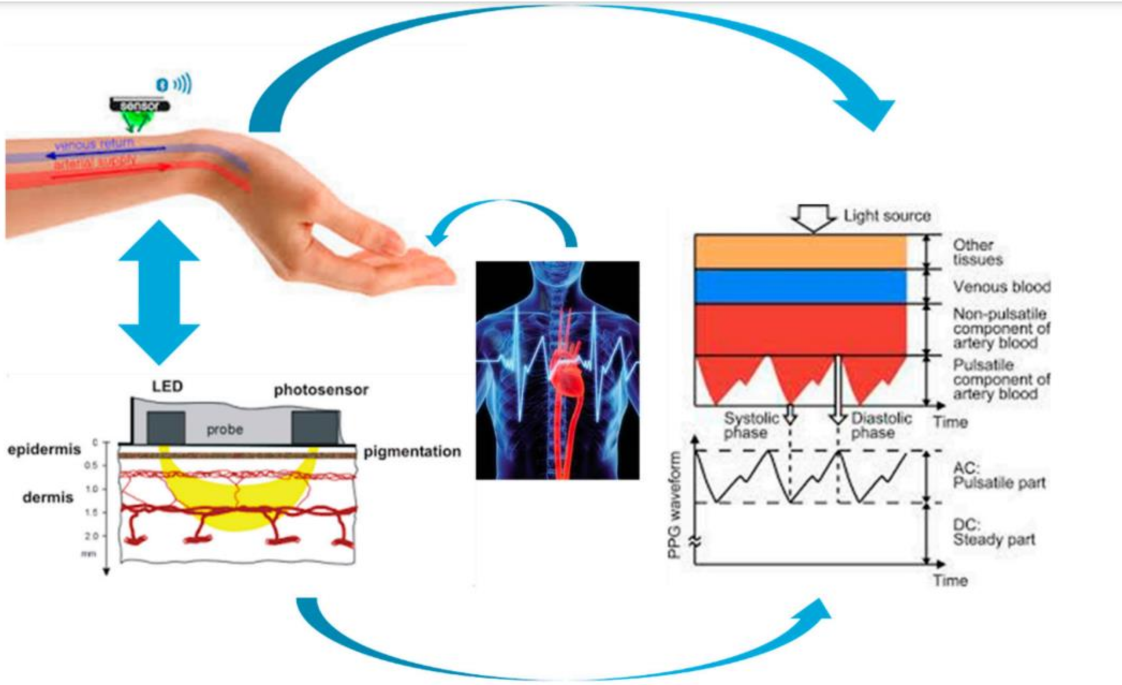


Figure 12. The physiological phenomena underlying photoplethysmographic (PPG) pattern formation [63].

Some researchers use algorithm methods, such as, the fast Fourier transform (FFT) that converts a signal into separated spectral parts providing information about the frequency of the signal and independent component analysis (ICA) (see Figure 13).

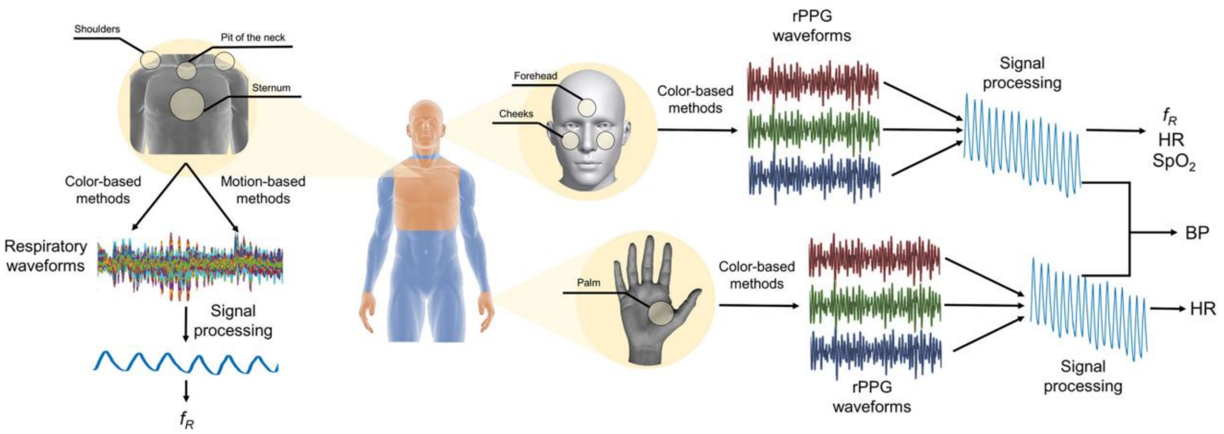


Figure 13. Measurement sites of the body and principal steps for extracting SpO2 and heart beatings per minute. [43].

The formula used to calculate the SpO2 can be based in the AC and DC of the blue and green channel [44].

$$SpO_2 = A - B\,\frac{AC_{RED}/DC_{RED}}{AC_{BLUE}/DC_{BLUE}} \tag{1}$$

To determine the cardiac frequency, previous studies have shown that the green channel has stronger plethysmograph signal [46] (see Figure 15) not being so sensitive the readings in case the patient performed physical activity like the red channel. Nevertheless, any channel (ch), red, green, and blue can be normalized (x') via a function where μ is the average and σ the standard deviation of the function $x_{ch}(t)$ respectively.

$$x'_{ch}(t) = \frac{x_{ch}(t) - \mu_{ch}}{\sigma_{ch}} \tag{2}$$

The beatings per minute can be obtained by counting the systolic peaks during the period of one minute. Figure 14 shows the systolic peaks from a PPG signal.

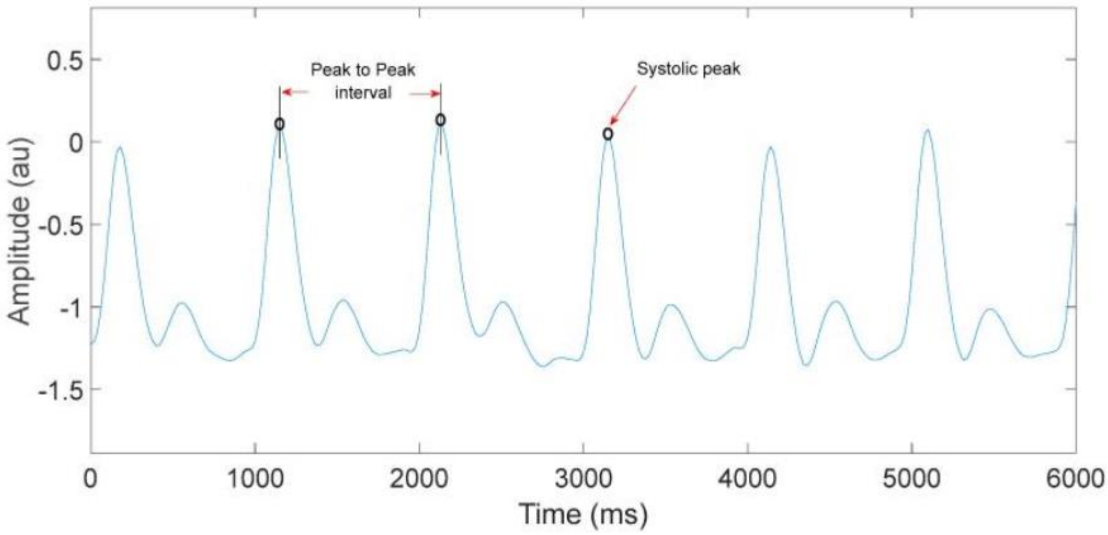


Figure 14. Systolic peaks and peak-to-peak intervals of a PPG signal [64].

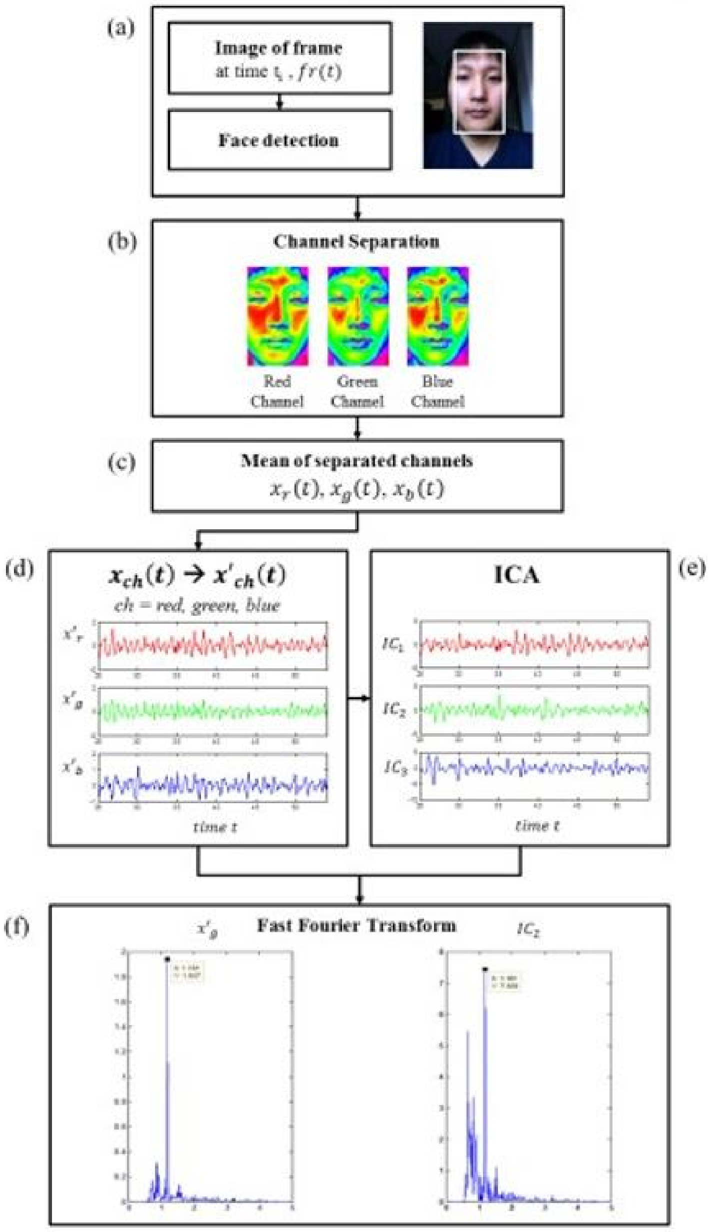


Figure 15. Heart rate calculation [45].

The treatment of the PPG signal and the use of the algorithms allow to determine vital signs like the cardiac frequency.

In many other researches, the beatings per minute (BPM) calculation by a camera shows close results to the ones reported by medical devices. The values obtained by a software/prototype can be compared with the ECG values (at 1000 Hz), mainly for the green channel. There are many AI for computer vision studies that use the region of interest (ROI) detection mixed with the fast Fourier transforms [46]. The accuracy of the values reported has to be high and have a low error margin when compared with other equipment. Processes like joint approximation diagonalization of eigen-matrices (JADE) to separate observed mixed signals into latent source signals and FFT (ECG uses the Fourier series) allows to calculate the vital signs values based on the spectrum considering duration, frequency and distance, the analysis should take in consideration noise and luminosity.

OpenCV [67] is an open-source library with a set of preprogrammed methods. Some of its algorithms allow to obtain the ROI and later divide the capture into 3 independent components (ICA) [46]. The 3 divisions can be normalized before applying FFT and present the values of the 3 ICA with normalized red, green and blue (RGB) values. Studies mention that the green channel has a stronger plethysmographic signal.

This section analyzes the **#Hypothesis_2**.

2.4 Open Computer Vision

OpenCV functions include some that allow detecting the region of interest from a camera, to obtain the average of the green, blue and red channels among others that allow face recognition (see Figure 16), implementing augmented reality, to detect motion among other possibilities commonly used in artificial intelligence for computer vision.

The library can be called via the Python programming language and is commonly used in many research projects. The work of Jarin [68] shows an approach of obtaining the cardiac frequency based on a real-time facial recognition technique using OpenCV. The collection of programmed functions can be used for many cases like mobile robotics, face and gesture recognition, object detection among other possibilities.

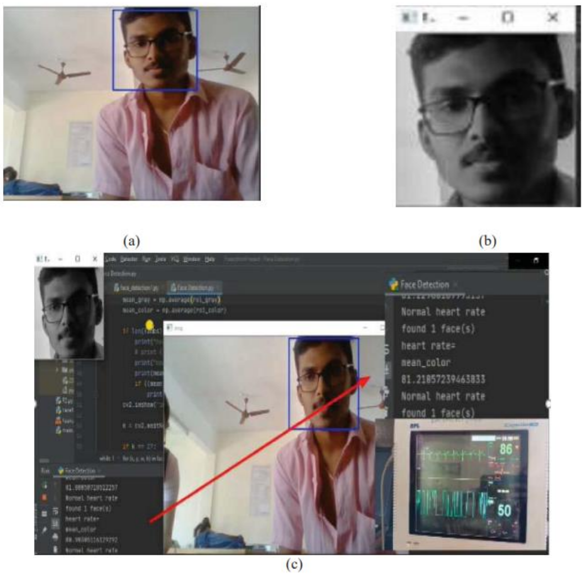


Figure 16. (a) Face detection. (b) Obtaining the green channel. (c) comparison of the obtained values with a medical device [68].

2.5 N-Tier Architecture

Based on Kambalyal [25] the N-tier architectures have advantages in terms of development speed, scalability, performance and availability. These multi-layered architectures allow to standardize applications and facilitate their flexibility. N represents the number of layers; if N=3, means that the model in cause is the 3-layer model. The study of Seongbok [26] compares the network performance between 2 tier and 3 tier networks (see Figure 17).

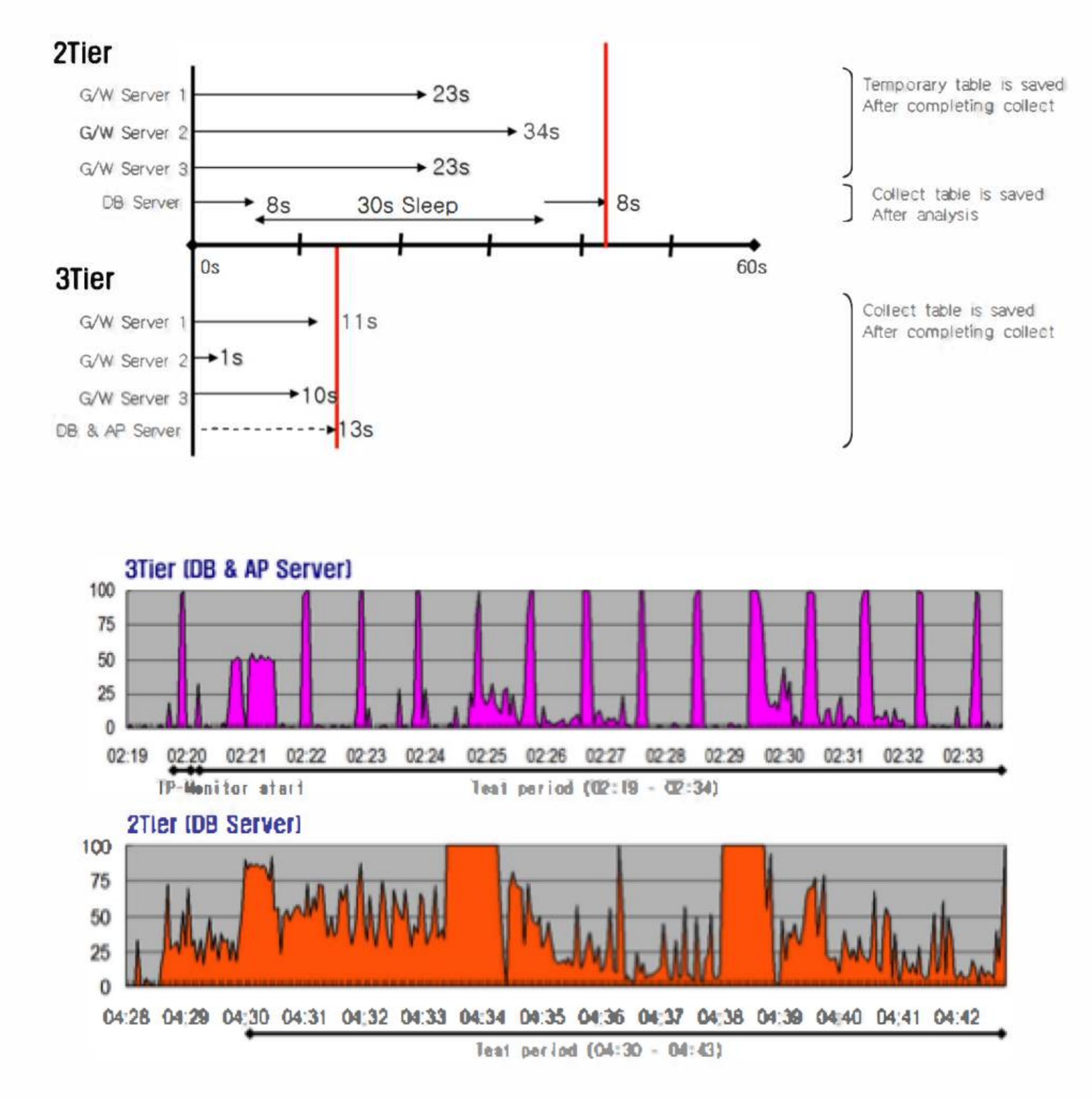


Figure 17. Examples of ping test and CPU usage between 2-tier and 3 tiers [26].

N-Tier architectures are client-server architectures, in which, functions such as presentation, application processing and data management are physically separated. When separating an application into layers, developers have the option to change or add a specific layer instead of redoing the entire application. It provides a model by which programmers can use to create flexible and reusable applications. The 3-tier architecture may or may not be followed in other software design patterns such as MVC (Model View Controller) [27] which is commonly used in .Net and Java for application development. A three-tier architecture is typically composed of a presentation layer, an application layer, and a data storage layer and can be ran on a separate processor.

The presentation layer is where the application layout is displayed, corresponds to the highest level of the application where users can access directly from a web page or the operating system graphical user interface (in so-called standalone applications). The main function of this layer is that the tasks and results are easy for the user to understand, includes the interfaces and what the user sees, thus communicating with the other layers of the network.

The application layer acts as a control of where business logic, rules, algorithms and other features are located, and is in an intermediate position, moving and processing data between the two adjusting layers. This layer makes the coordination and control of the application, processes the commands, makes logical decisions, evaluates and performs calculations and also controls the functionality of an application by performing detailed processing [28].

The data layer is the lowest layer and has a strong relationship with the database. The information is passed on for processing and then returned to the user. Information is saved and retrieved (backups, restores) from the databases or file systems.

By analyzing the study from Xu [29], we can find processes of calling from the presentation to the business layer and the use of ajax (set of asynchronous techniques for web development) on the logic layer (Figure 18).

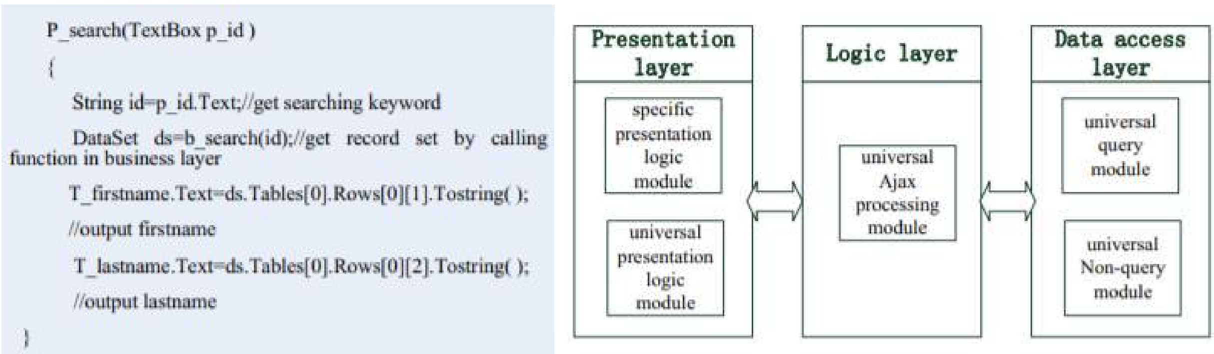


Figure 18. Presentation layer calls the function in the business logic layer [29].

2.6 Web Services and Application Programming Interface

Web services and service oriented computing reduce the costs of building new systems for a variety of reasons. They allow communication between applications or part of the application so they can use existing applications and services without having to develop the application from scratch.

A web service is a way for two machines to communicate over a network, and an application programming interface (API) is an interface that uses a set of definitions and protocols allowing one application to communicate with another application. Extensible markup language (XML) or JavaScript object notation (JSON) among others are used to tag data, simple object access protocol (SOAP) is a messaging protocol used to exchange structured information, web services description language (WSDL) is primarily for describing available services via XML and universal description discovery and integration (UDDI) is for listing which services are available. These can be searchable over the network and can also be called properly [30]. When called, web services can provide functionalities to the customer who calls this web service.

Representational state transfer (REST) is an architectural standard based on a set of rules, standards and guidelines on how to develop a web API. An agreed system of structuring an API saves time on decision-making as well as time on understanding how to use it (see Figure 19).

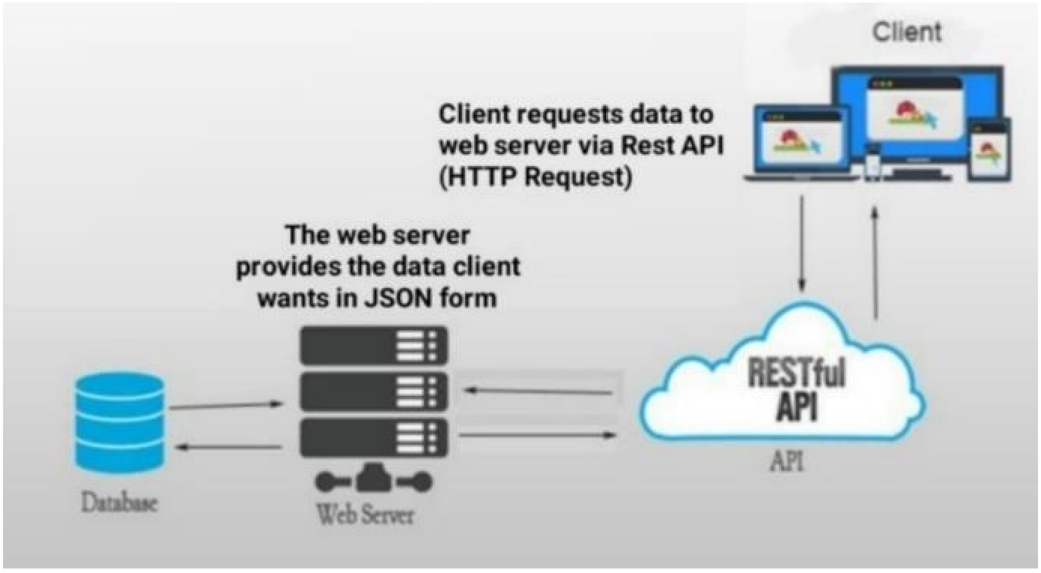


Figure 19. RESTful API interacting between client computer and database [31].

In the development process, the use of web services allows the application to be divided into different layers, such as front end, back end and data layer, which has many advantages because it will not be needed to change the entire application when a bug or problem arises. Facilitates the development as it allows the bug fix to be treated only locally and does not affect the rest of the application. This development methodology is based on the reuse of components obtained by the network; it does not have interoperability issues (compatibility between operating systems), as well as incompatibility between the development languages used and are not dependent on the characteristics of client computers, so they are cheaper and easier to incorporate.

Web services use standard web protocols like hypertext transfer protocol (HTTP) or hypertext transfer protocol secure (HTTPS) to interoperate, communicate, and exchange data messages, which have a standard visibility in extensible markup language (XML) or JavaScript object notation, among others over the Internet. They can be tested using specific programs like Postman, Swagger and SoapUI Pro. During development the hypertext transfer protocol standard response code allows to check if the object is passing from one system to another, usually the HTTP 200 status response code indicates that the request has succeeded when passing from one point to another. Web services use open standards that any part of the hardware or software program can access and can be written once and used many times or in different ways. The open standards used by web services enable to connect processes more easily and reliably. Web services also allow to bring different systems together, avoiding the need to build new systems from scratch and with less costs [32]. API is a very broad term. It is usually like a piece of code that communicates with another. In web development, the API usually refers to the way we retrieve information from an online service. The API documentation provides a list of uniform resource locators (URLs), query parameters, and other information on how to make an API request and informs what type of response will be given for each query (see Figure 20).

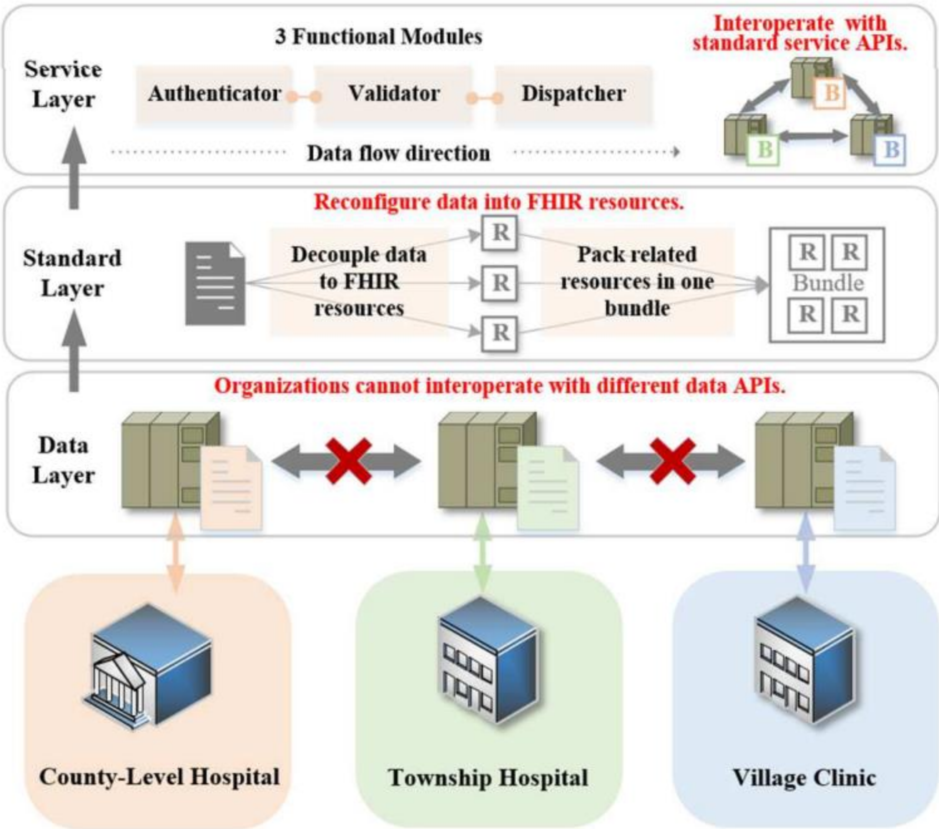


Figure 20. Logical architecture with Tiers and APIs. [33].

Representational state transfer (REST) is an architectural pattern based on a set of rules /standards/guidelines on how to create a web API. Since there are several ways to do this, having an agreed system of structuring an API saves time in making decisions as well as saves time in understanding how to use it. RESTful refers to the implementation of web services that use the REST architecture, which can use the HTTP, GET, POST, PUT, and DELETE methods. To understand service-oriented architecture (SOA), we must start with a clear understanding of the term service. A service is a function that is well defined, independent and does not depend on the context or state of other services. Web services technology is the most common connection technology in service-oriented architectures. The availability and effective utilization of these new features and capabilities requires the restructuring of many existing applications. SOA comes at a time when there was a pressing need for architectural conversion. Chou [34] studied the design patterns of REST APIs (see Figure 21).

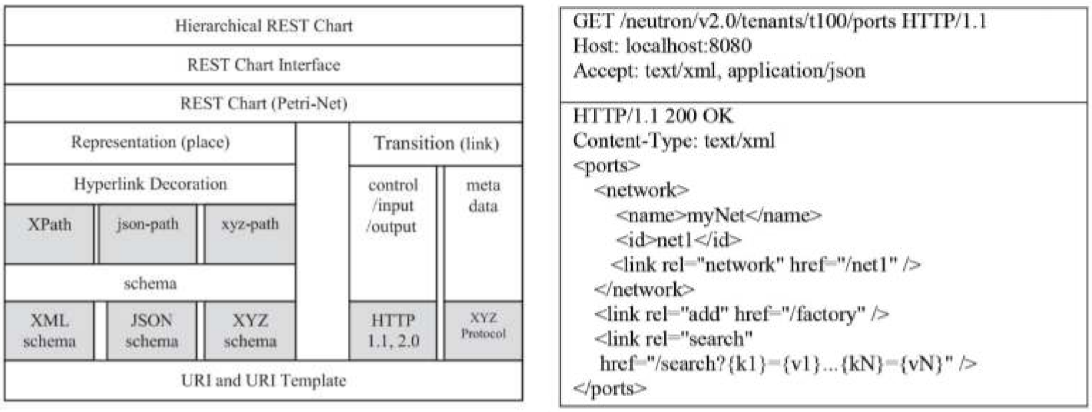
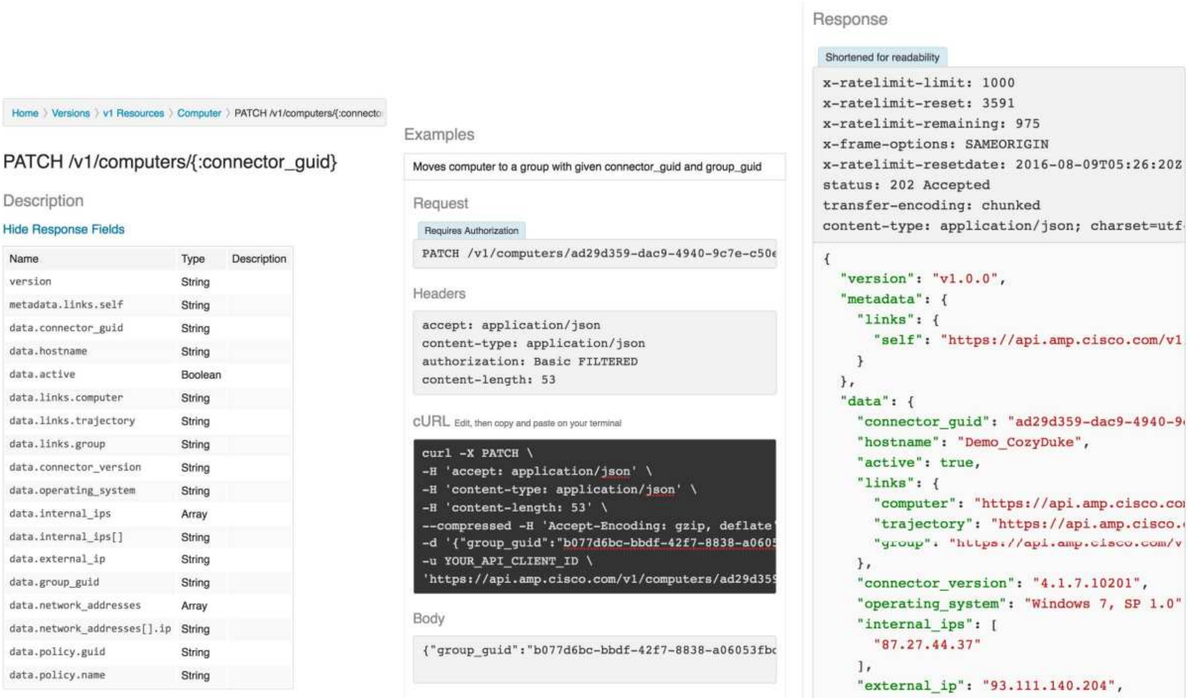


Figure 21. Modular architecture of REST chart, and a Get example [34].

REST APIs can be implemented via Spring MVC and Spring Boot [35], using technologies like Hibernate or MyBatis to connect with the database. The work of Sohan [36], shows a process of updating the documentation of the APIs via SpyREST (see Figure 22).



(b) SpyREST Analyzed API Structure (c) SpyREST Recorded API Request (d) SpyREST Recorded API Response

Figure 22. Example of the REST API documentation from Cisco using SpyREST [36].

3. Applications for the Physicians

This section describes the application for the physicians named AI Care developed in the scope of this research, which has two main divisions: The first has a primary care approach where the vital signs are described, and how they were obtained via a camera and web and a second division with a secondary care perspective, more focused in a medical specialty where the analysis is done for a certain disease or a certain organ. This study took in consideration the analysis of the pathologies: covid-19 and brain tumor, and the organs studied were the heart, lungs, and brain.

The dissertation aims to defend a new process of online consultation and diagnosis adding features that traditional processes do not have such as providing the vital signs on real time via a camera, a medical image uploader that based on predictions mentions if a certain disease is present and a web stethoscope that displays a spectrum of frequencies making the diagnosis process easier during video chat consultations. Traditional processes can be improved with online diagnosis features like the ones described in this chapter based on artificial intelligence mechanisms to facilitate the work of the physician.

3.1 Contextualization and Overview

Using artificial intelligence for computer vision, the vital signs like the body temperature, blood pressure, systolic values, diastolic values, cardiac frequency, oxygen saturation and respiratory rate can be obtained and stored, in order to understand the health status of the patient (see Figure 23).

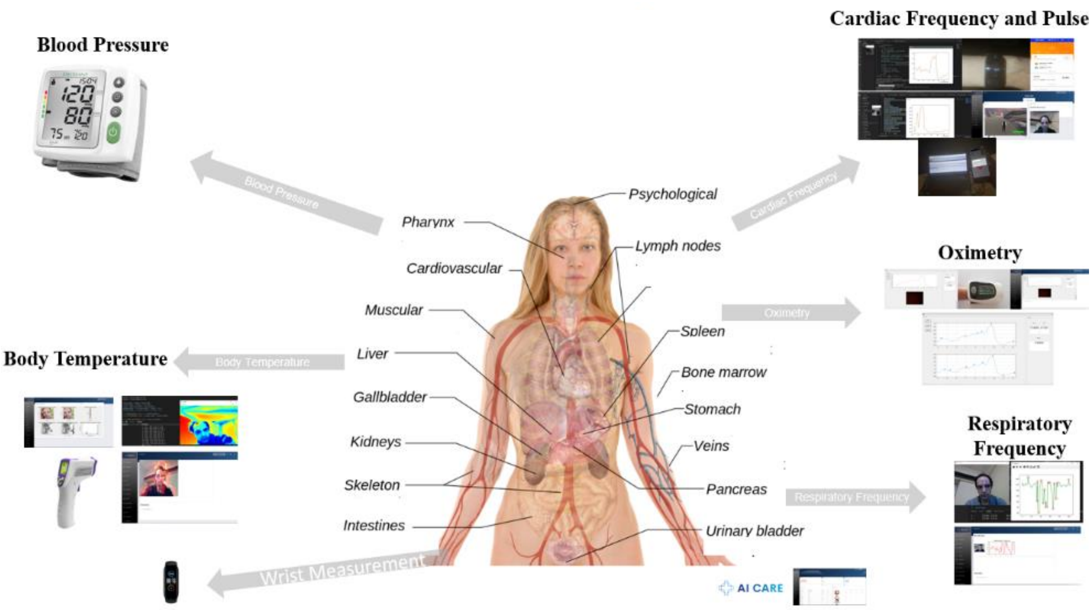


Figure 23. Overview of the processes and artefacts to obtain the vital signs.

With the objective to improve the diagnosis of secondary care, this study focused on 3 organs: heart, brain, and lungs as a process to better check the healthy status of these body parts. Several applications were developed: a stethoscope, a medical image classificatory, an online chat, artificial intelligence systems that obtain the vital signs data, and an integrator that stores the information in a MySQL database and manages the information, so physicians can have a more complete archive of a certain patient. The dissertation presents an integrated solution developed mainly in hypertext preprocessor (PHP), Python and JavaScript allowing: the application of deep learning on the classification of X-Rays, CT scans and MRI scans, to obtain spectrograms via web, and also to read and store the vital signals of the patient using algorithms of computer vision and software engineering practices.

This chapter shows the work performed to implement artificial intelligence mechanisms on the healthcare web systems when interacting with the patients and to improve the display of information. From a primary care perspective, the presented solution is based on the obtention of the vital signs like body temperature, blood pressure, systolic values, diastolic values, cardiac frequency, oxygen saturation and respiratory rate. On the secondary care, the research is focused on three organs: heart, lungs and brain, a process for which a web stethoscope was developed showing the spectrogram obtained, helping the physicians on their diagnosis and a classifier using deep learning to treat the X-ray, CT scans and MRI scans after uploading in terms of informing if there is a possible disease using the prediction made by the model visual geometry group (CNN architecture that can be used to classify images) with 16 layers. The diseases considered were covid-19 for X-rays and CT scans of the thorax and brain tumor for MRI scans of the brain. The main web application that integrates several artificial intelligent systems is called "AI Care" (see Figure 24).

Figure 24. Schematic of the proposed solution.

On a primary care point of view, the objective is to perform some of the healthcare activities online and virtual consultations aided with a video chat developed in NodeJS combined with access to the clinical data of the patients during the conversation and obtaining the vital signs in real time. On a secondary care point of view, this study focuses on three organs: heart, brain and lungs; in order to better check the healthy status of these organs, two applications were developed: a stethoscope that displays a spectrogram of the sound signal and a medical images uploader for disease classification.

The AI care application has an online chat with vital signs data and an integrator that stores the information in a MySQL database and manages the information, so physicians can have a more complete archive of a certain patient. The database has 19 tables, some of them connected via foreign keys (Figure 25), where the information inserted by the physician is stored.

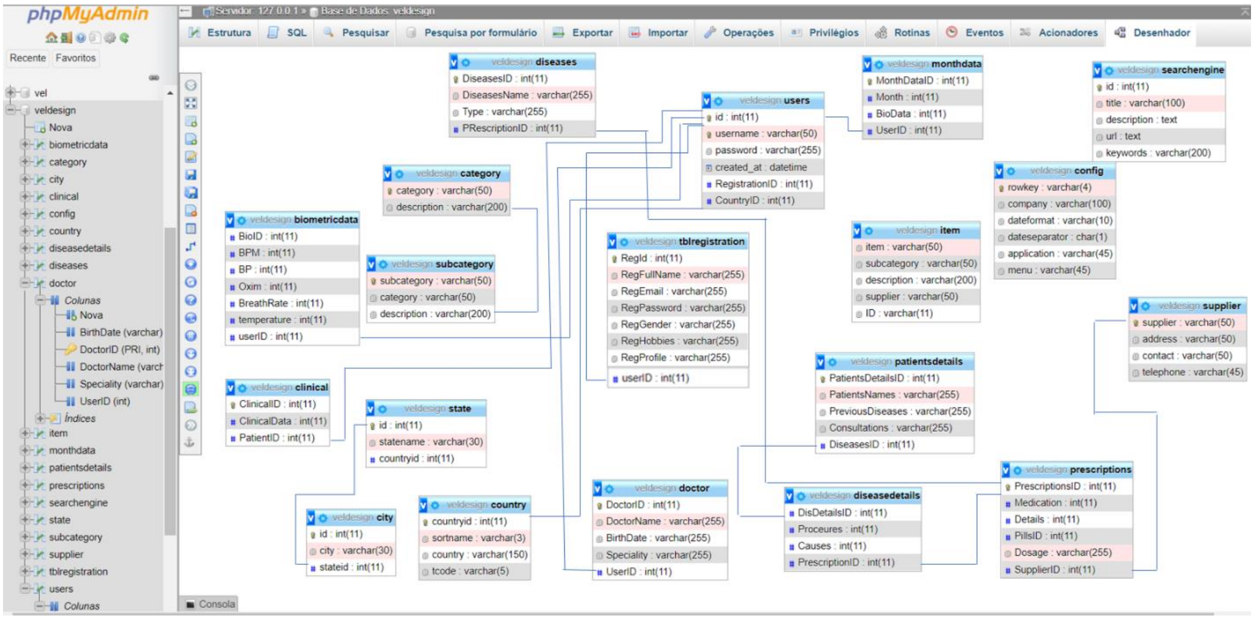


Figure 25. Entity relationship model of the AI Care database.

Some functional requirements obtained after the user stories are:

- The system must obtain the vital signs.
- The system must store the inserted values by the healthcare professional.
- The system must have a spectrogram that reads the sounds obtained by a stethoscope.
- The system should show the prediction of the existence of a disease after uploading a medical image.
- The system should have a login system.
- The system must integrate all applications in an online program.

The architecture follows a 3-tier standard (Figure 26) allowing to use application programming interfaces, on the presentation layer there are views and controllers, on the logic layer the processes and the controllers to perform the functions and on the data layer the models and entities and the controllers, the connection to the database used the function “mysqli_connect”.

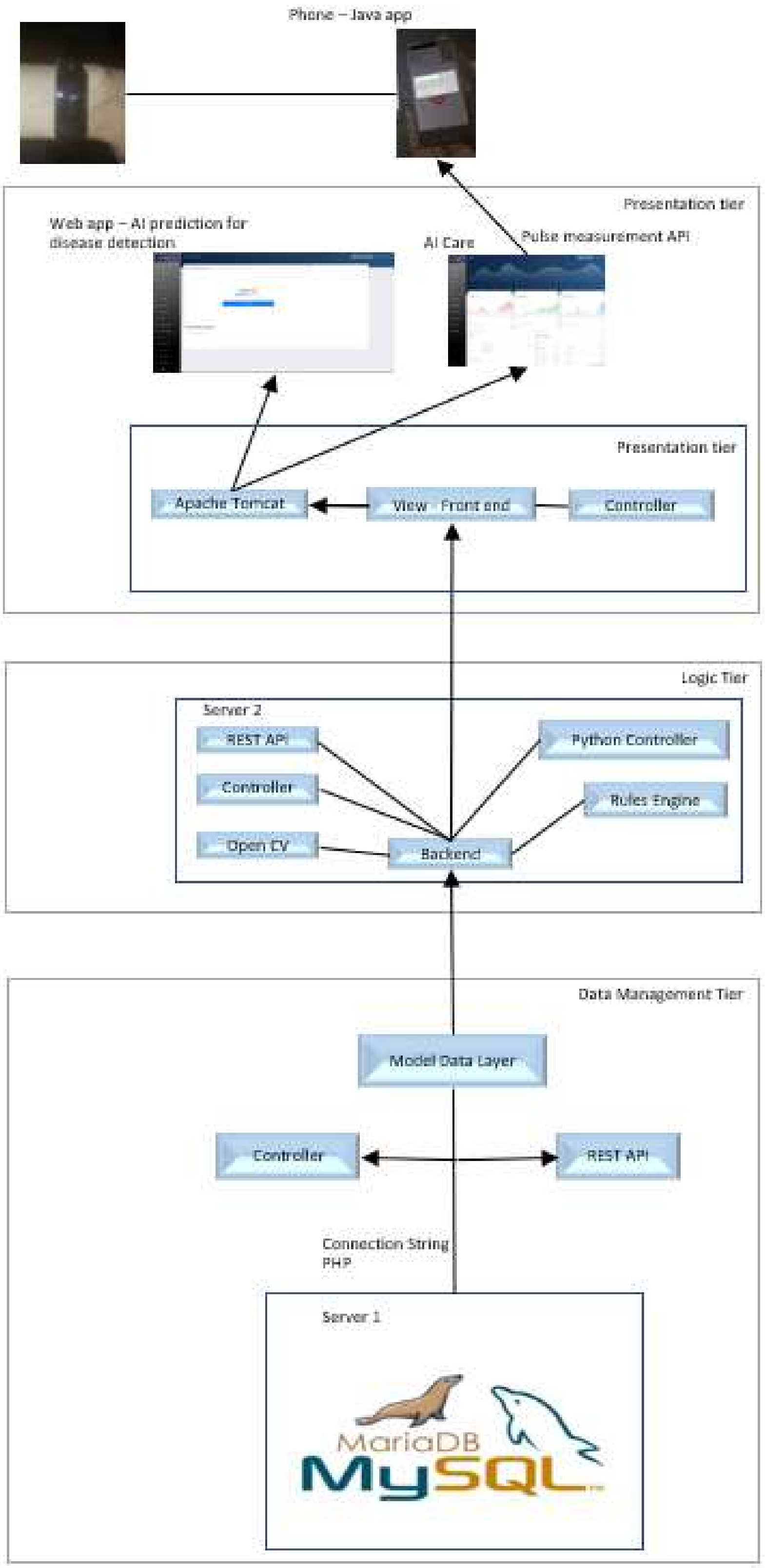


Figure 26. Proposed architecture for the solution.

This analysis takes in consideration **#Hypothesis_5** although it is possible to store the values obtained by the Python application to a database like MySQL **#Hypothesis_6**.

3.2 Online Consultations

Concerning the objective of making a medical analysis more effective, the presence of the physician during the process is important because he can provide clinical information concerning the readings obtained and inform the patient on how to proceed, to fill this need an online video chat was developed mainly in NodeJS and integrated to the solution making easier the process of virtual consultations (see Figure 27).

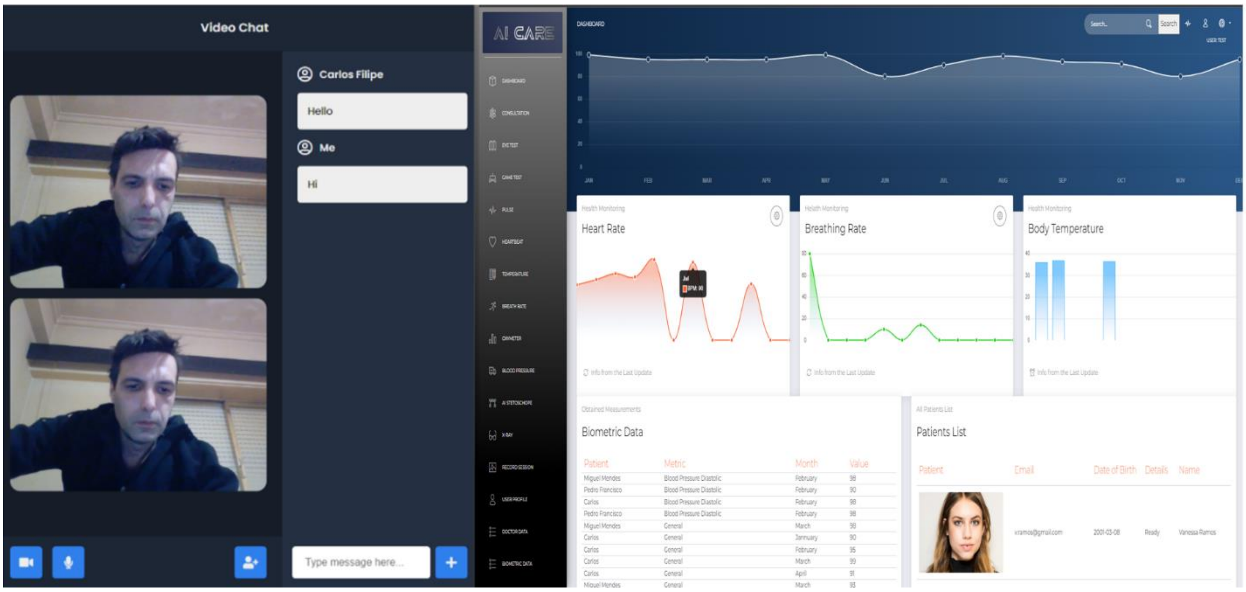


Figure 27. During the chat, the physician can visualize the historical data of the patient. Adapted from the code of [51].

3.3 Web Development

The AI Care web application works as an integrator of several applications in one system. The program uses a 3-tier architecture having a user interface or presentation tier that displays the information, an application tier where data is processed and a data tier where the information is stored and managed.

The Python artificial intelligence applications were placed online using Flask and allow to perform certain functions like obtaining vital signs or mention if an uploaded medical image has one of the studied diseases which in this case were covid-19 and brain tumor.

The system uses a set of application programming interfaces that allow to perform certain tasks and services. Using a service-oriented architecture with 3 tiers and the mechanisms of communication between applications facilitated the development. Many systems were constructed independently and added to a one final web solution that uses many programming languages like PHP, JavaScript, HTML among others.

By looking at the PHP file of the dashboard in Figure 28, we can see the code to initialize the session, after will check if the user is logged, in case it is not will redirect to the login page, next we can see the code that allows to connect to a MySQL database mentioning the internet protocol and the name of the database followed by HTML code that calls the google maps API and also with esthetical details of the page.

```
<?php
// Initialize the session
session_start();

 // Initialize the session
 error_reporting(E_ALL ^ E_NOTICE);

// Check if the user is logged in, if not then redirect him to login page
if(!isset($_SESSION["loggedin"]) || $_SESSION["loggedin"] !== true){
    header("location: login.php");
    exit;
}
?>
<?php
        $con = new mysqli("localhost","root","","vel");
?>

<!DOCTYPE html>
<html lang="en">

<head>
  <meta charset="utf-8" />
  <link rel="apple-touch-icon" sizes="76x76" href="../assets/img/apple-icon.png">
  <link rel="icon" type="image/png" href="../assets/img/favicon.png">
  <meta http-equiv="X-UA-Compatible" content="IE=edge,chrome=1" />
  <title>
    AI Care
  </title>
  <meta content='width=device-width, initial-scale=1.0, maximum-scale=1.0, user-scalable=0, shrink-to-fit=no' name='viewport' />
  <!--     Fonts and icons     -->
  <link href="https://fonts.googleapis.com/css?family=Montserrat:400,700,200" rel="stylesheet" />
  <link rel="stylesheet" href="https://use.fontawesome.com/releases/v5.7.1/css/all.css" integrity="sha384-fnmOCqbTlWIlj8LyTjo7mOUStjsKC4pO
  <!-- CSS Files -->
```

Figure 28. Part of the code used in a PHP file to generate the dashboard.

3.4 Primary Care Analysis Based in Obtaining the Vital Signs

Some primary care activities can be done online. This section shows a web process of diagnosing a patient taking in consideration the vital signs obtained via a camera sensor. For this presentation, the health reference values under this analysis are considered to be those that are, or are very close, to the currently considered normal for an adult user at rest (no physical activity, lying down or sitting), with no known pathologies and no acute disease symptoms.

Reference Values Considered in this Program:

Body temperature: 35.5º to 37.5º centigrade. **Systolic**: 90 to 140 mmHg. **Diastolic**: 60 to 90 mmHg. **Heart rate**: 60 to 80 beats per minute. **Oximetry**: oxygen saturation ≥ 95%. **Respiratory rate**: 12 to 18 breaths per minute.

The user of the program should ask the assistant physician for information about the values of the vital parameters adjusted to his case, taking into account his pathologies and other variables. The patient must have information that allows him to know how to proceed in case the parameters are breached. An example is the rise in temperature, which can be resolved frequently with medication that the patient should have at home and other body cooling measures. The maximum pikes of the cardiac frequency correspond to an inhale, the number of maximums in a minute is calculated providing the breathing rate in one minute (see Figure 29). The heart rate is measured using AI algorithms and a webcam sensor. The application also has a graphic showing the breathing variation.

The temperature is calculated based on the face detection (RGB) of the patient, by using specific functions of the OpenCV library and by applying formulas to the average of the green channel after placing a mask and a heatmap to the initial images obtained by the camera. The physician can visualize the vital signs for each patient (see Figure 30).

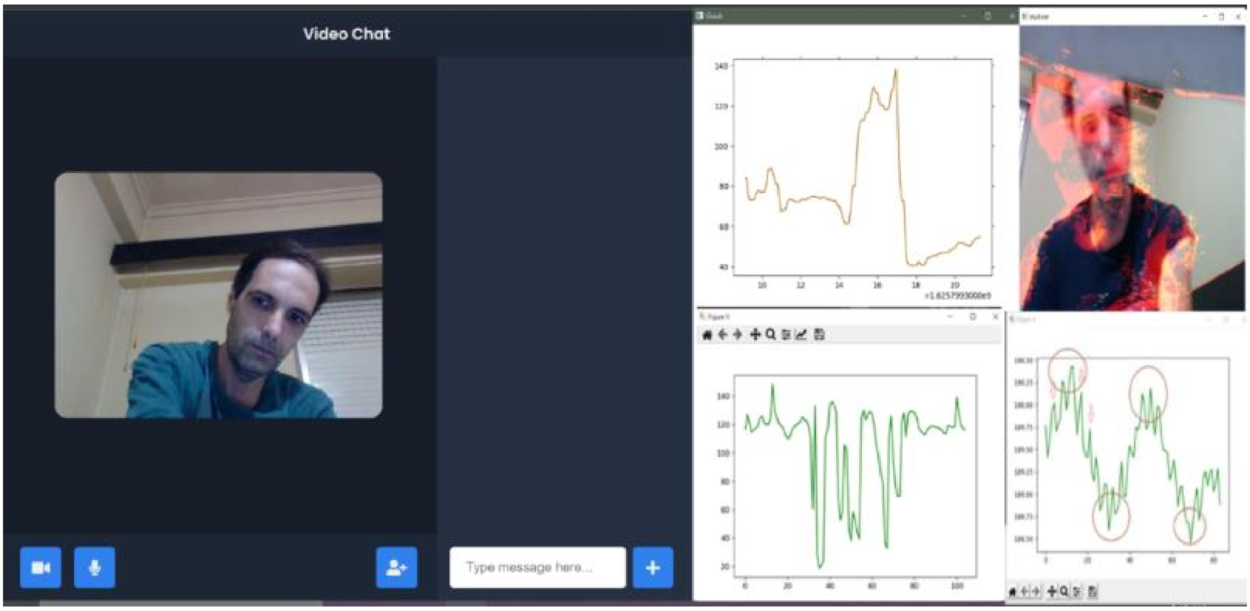


Figure 29. Analysis of the breath rate.

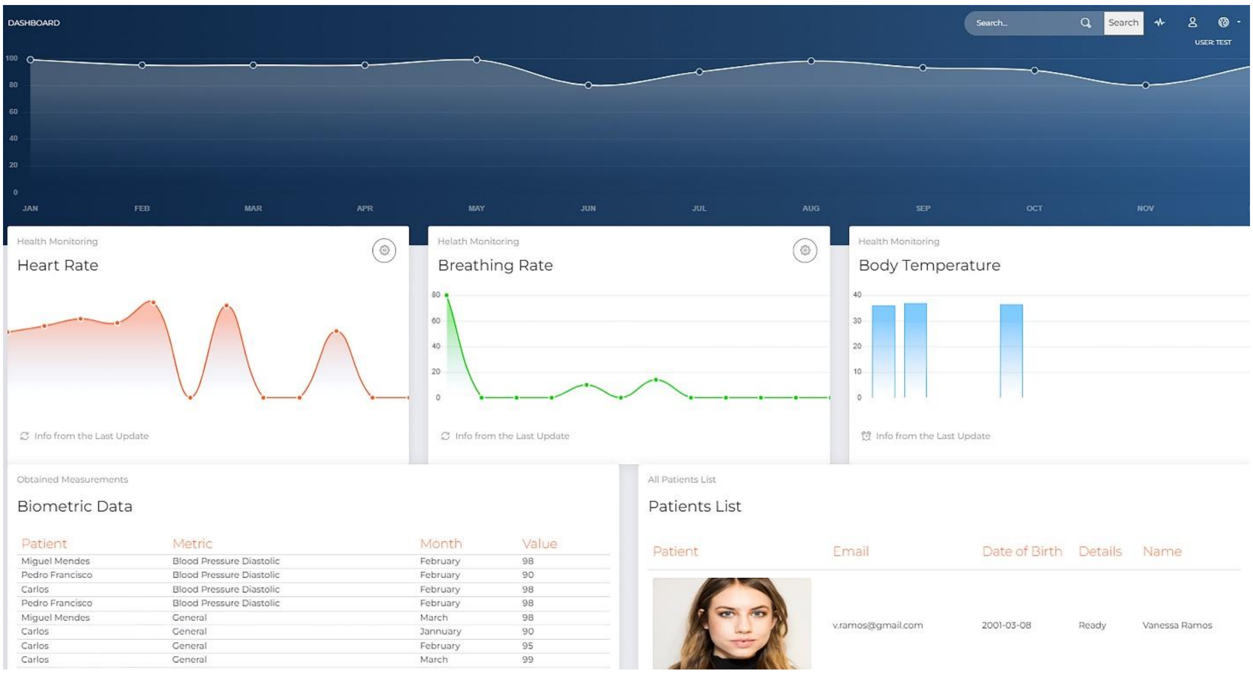


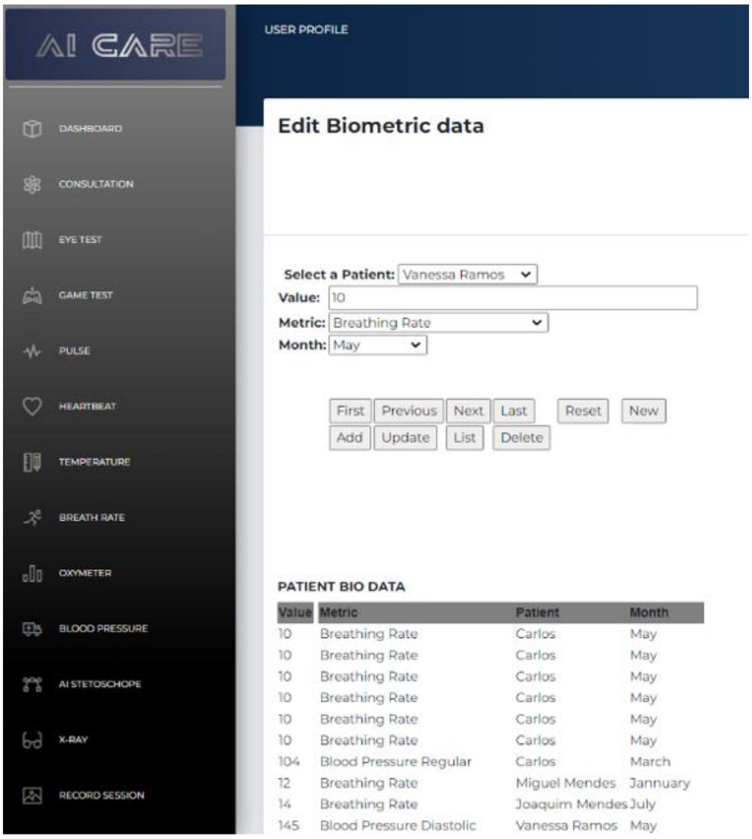
Figure 30. The AI Care application.

Concerning primary care activities and to improve the current online consultation process, this dissertation presents a prototype based on obtaining the vital signs during consultation for the physician, and also access to the patient history, aiming to facilitate the process of detecting possible diseases and triggering the emergency procedure based on the country where the user is placed without physical contact avoiding also the contagion of the covid-19 disease.

Currently it is possible to obtain the exact value of the vital signs: for blood pressure through the sphygmomanometer which also records the heart rate, concerning body temperature the actual values can be obtained with the thermometer; for the oxygen in the blood the correct values can be measured by an oximeter and heart rate can be obtained by different devices like the oximeters that also read this value, as do some sport watches and sphygmomanometers (blood pressure devices); Heart rate can also be assessed on arterial pulses (example given: on wrist and neck).

The data is inserted in the application by the physician after making the readings, this way avoids appearing wrong values that may occur during readings like the patient not being well positioned in front of the camera or low light scenarios (see Figure 31).

The healthcare professional should place the data freely taking in consideration the correct values and assign an overall health state in percentage, presenting lower values for cases that have one or more of the vital signs readings outside the threshold.



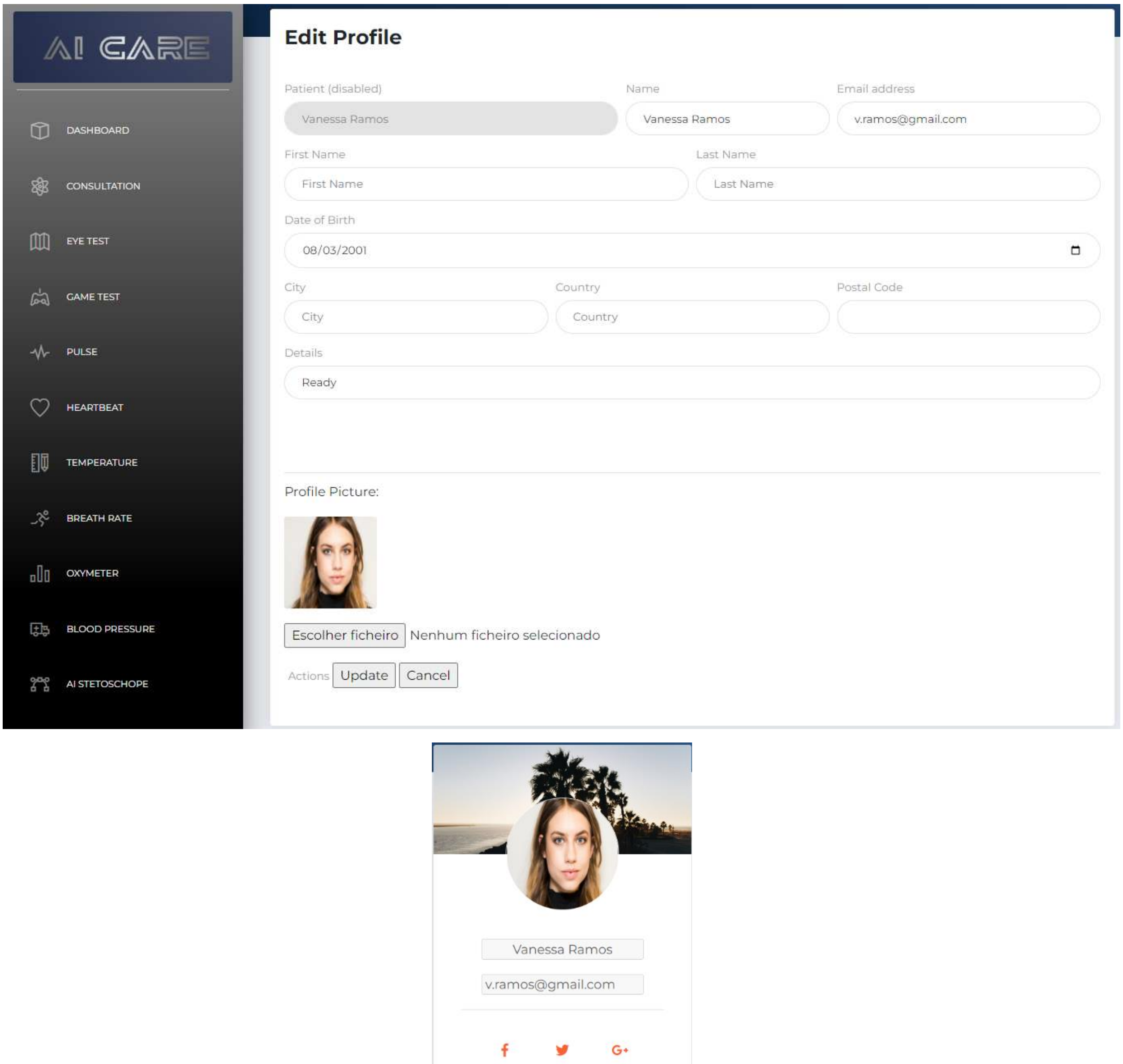


Figure 31. Data for a specific patient.

Whenever the program detects values above or below those recorded as a reference, an emergency procedure should be triggered, and the user can communicate the problem to the attending physician or the professional who will assist him.

The patient should have information about the signs and symptoms that require urgent/emergent medical intervention, and, if possible, help from third parties, even if the parameter measurements are in the range considered normal in the program. Some examples are some types of chest pain (thoracic pain), sudden miss of air, signs of rapidly worsening breathlessness, deviation of the labial commissure, lack of strength in one of the limbs, among others (some possible emergency situations are chest pain, feeling faint, dizziness, shortness of breath and lack of strength). The vital signs allow physicians to understand the health state of a patient and determine the severity level.

3.5 Body Temperature

Body temperature refers to the production of heat in the body and the mechanisms for its regulation and maintenance, essential to maintain systemic homeostasis (stability that the body needs to perform its functions properly). The usage of OpenCV and Python allows to get the temperature values via web camera. The program requires the installation of OpenCV libraries. Artificial intelligence for computer vision mechanisms were used to achieve the results, the application has to identify the region of interest which in this case is the face of the user before displaying the body temperature value. The provided solution (see Figure 32) used the Python programming language and was based on applying a mask to the heatmap of the images obtained by the infrared camera and after applying the formulas to the red, green and blue (RGB) values obtained, mainly the average of the green channel in order to obtain the body temperature using functions of the OpenCV library. The application was placed web via Flask.

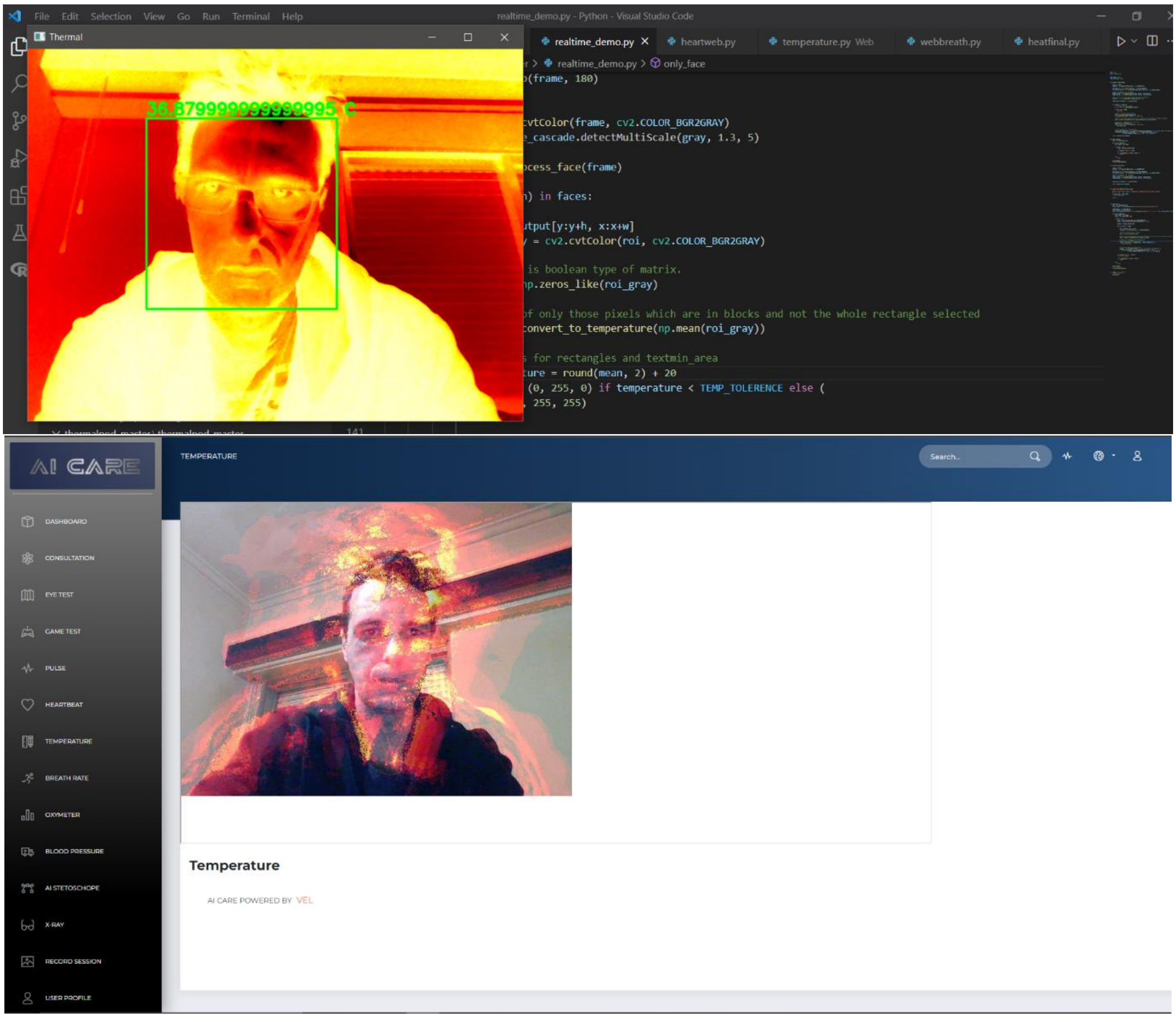


Figure 32. Obtaining body temperature via Python. Adapted from the code [53].

The approach followed considered **#Hypothesis_1** and **#Hypothesis_3**.

3.6 Blood Pressure

Blood pressure or blood tension is the force that the blood exerts on the walls of the arteries during its circulation, and results in two measures:

• Systolic blood pressure or "maximum" blood pressure: appears first and measures the force with which the heart contracts and "expels" the blood from its interior.

• Diastolic blood pressure or "minimum" blood pressure: this is the second value and concerns the measurement of pressure when the heart relaxes between each beat.

The reading of blood pressure is usually measured in millimeters of mercury (mmHg). When blood pressure is normal, it allows blood to be distributed throughout the body, reaching all organs. If the blood pressure is chronically high (hypertension) or when it increases suddenly, it has negative consequences for health, being responsible, for example, for cerebrovascular accidents, cardiac infarctions (death of heart cells), among other possibilities. For cases where blood pressure is too low (hypotension) blood flow on cells can decrease, compromising the nutrition and oxygenation of the cells, including brain cells. An approach to obtain the blood pressure was done via a mobile application developed in Java to obtain these values using the camera of the phone and by detecting the face of the user. Other researchers use other approaches like placing the finger over the phone camera with flashlight to measure the force that the blood exerts on the walls of the arteries.

The system was developed in Java using Android Studio and is based on treating the RGB values obtained by the phone camera of a detected face. The project still needs some adjustments to increase the accuracy (see Figure 33).

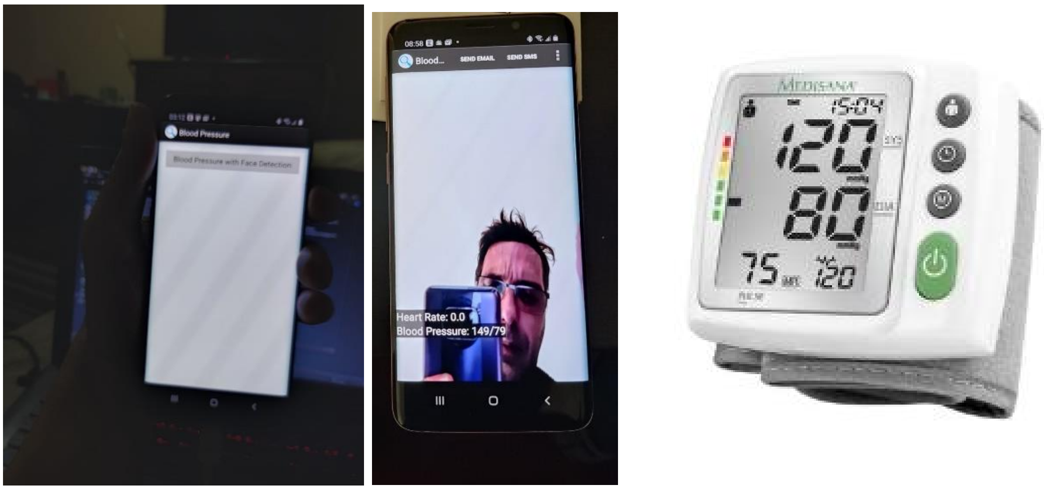
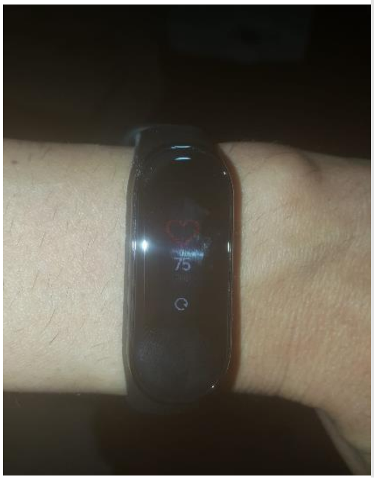


Figure 33. Application developed in Java for mobile, adapted from the code [66] and a Pulse Blood Pressure Monitor.

The approach followed considered **#Hypothesis_1** and **#Hypothesis_3**.

3.7 Cardiac Frequency

The cardiac frequency rate is the number of times your heart beats per minute. Changes in heart rate may indicate the existence of cardiac and non-cardiac pathologies and may compromise the nutrition and oxygenation of the cells, including the brain cells; in order to measure the heartbeats, an application was developed that measures the cardiac frequency in real time with the use of Python (see Figure 34) that is based in computer vision. Appearing on the monitor the reading obtained. The results from the webcam detection were compared and tested with the ones provided by medical devices and the clock sensor.



```
import cv2
import time
import numpy as nump
from matplotlib import pyplot as plot

figura = plot.figure()
auxiliar = figura.add_subplot(111)
coracaobeat_counter = 128
captured = cv2.cv2.VideoCapture(0)
captured.set(cv2.CAP_PROP_FRAME_HEIGHT, 1280)
captured.set(cv2.CAP_PROP_FRAME_WIDTH, 1920)
captured.set(cv2.CAP_PROP_FPS, 60)

coracaobeatvalues = [0]*coracaobeat_counter
timescoracaobeat = [time.time()]*coracaobeat_counter

while(True):

    x, y, w, h = 950, 300, 500, 500
    ret, frame = captured.read()
    picture = cv2.cvtColor(frame, cv2.COLOR_BGR2GRAY)
    imagemmcut = picture[y:y + h, x:x + w]
    coracaobeatvalues = coracaobeatvalues[1:] + [nump.average(imagemmcut)]
    timescoracaobeat = timescoracaobeat[1:] + [time.time()]
    auxiliar.plot(timescoracaobeat, coracaobeatvalues)
    figura.canvas.draw()
    plotimagemm = nump.fromstring(figura.canvas.tostring_rgb(),
                                  dtype=nump.uint8, sep='')
    plotimagemm = plotimagemm.reshape(figura.canvas.get_width_height()[::-1] + (3,))
    plot.cla()

    cv2.imshow('Graph', plotimagemm)
    cv2.imshow('Crop', imagemmcut)
    if cv2.waitKey(1) & 0xFF == ord('q'):
        break
captured.release()
cv2.destroyAllWindows()
```

Figure 34. Heartbeat detection and comparison.

By analyzing the Python code, we can see that the values obtained by the green channel allowed to determine the heart frequency. The information provided will facilitate a clinical analysis. The application will track the face of the user first and afterwards will report the heartbeat in real time. The heartbeat measurement can be obtained via a web application with the use of OpenCV.

Pulse measurement of the fingerprints is one of the several functionalities of AI Care being a bit related with the heartbeat detection project. It is also calculating the number of heart beatings but instead of measuring above chest, it is measuring the pulse from the fingerprint. In case the readings are too different from these two places, the patient most likely is facing a situation of cardiac arrhythmia and should see his physician.

The application should have an alarm system that triggers a contact to the corresponding medical institution according with the national emergency system of the country in case. The user has to place his finger on the phone camera for a few seconds and check if the light is on. The measurement process is different from the one used in the heartbeat via webcam. After getting the reading, the user can press a button on the mobile Java application that will send the information to the AI Care web application, which will add this value to his profile, store in the database and report on the system the readings obtained every time the clinical record is checked.

The technologies used for the mobile application were Java, Android Studio and APIs and concerning the web application was used PHP, MySQL and JavaScript mainly. A website was developed to obtain the information obtained from the mobile phone using the open source PubNub API, allowing the verification of the data obtained by the mobile phone. The website shown in Figure 35 was made with HTML, JavaScript and CSS languages, using an API that allows the passage of information between the phone and the website. The developed mobile application in Java reads the heartbeat via the phone and sends the information obtained to the website.

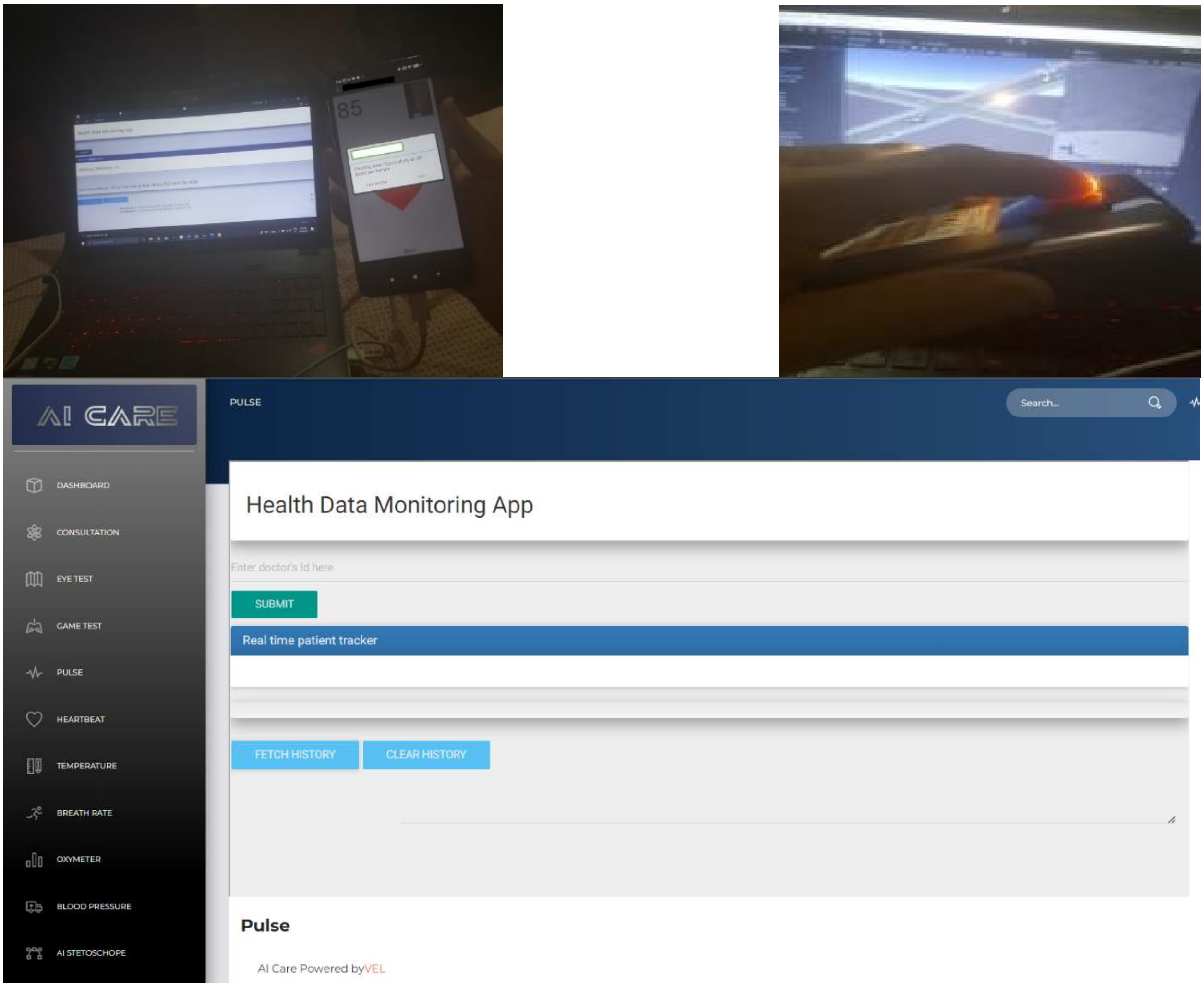


Figure 35. Detection of heartbeats via finger from the phone camera with flashlight (light required for reading) and the web application. Use of the API provided by Pubnub [54].

The approach followed considered **#Hypothesis_1** and **#Hypothesis_3**.

3.8 Oximetry

The Oximetry is a test that lets you know how much oxygen is being carried in the blood. The oxygen level measured with an oximeter is called the oxygen saturation level (SpO2). SpO2 is the percentage of oxygen that blood carries (in red blood cells) compared to its maximum carrying capacity on arteries. The lack of oxygen in the blood reduces its supply to the cells and may be inadequate for its needs, a condition that can cause serious cell damage and even lead to death. The SpO2 percentage was obtained with MatLab. To perform this test, it is required to use appropriate lighting and placing the thumb close to the web camera with flashlight. The formula used to calculate the SpO2 was based in the AC and DC of the blue and green channel [44].

$$SpO_2 = A - B\,\frac{AC_{RED}/DC_{RED}}{AC_{BLUE}/DC_{BLUE}} \tag{1}$$

The application was developed in MatLab taking in consideration the red, green and blue values obtained by the web camera while pressing the thumb with flashlight allowing to measure the percentage of oxygen in the blood arteries. The application also measures the heart beatings per minute and has some similarities with the processes used in oximeters (see Figure 36).

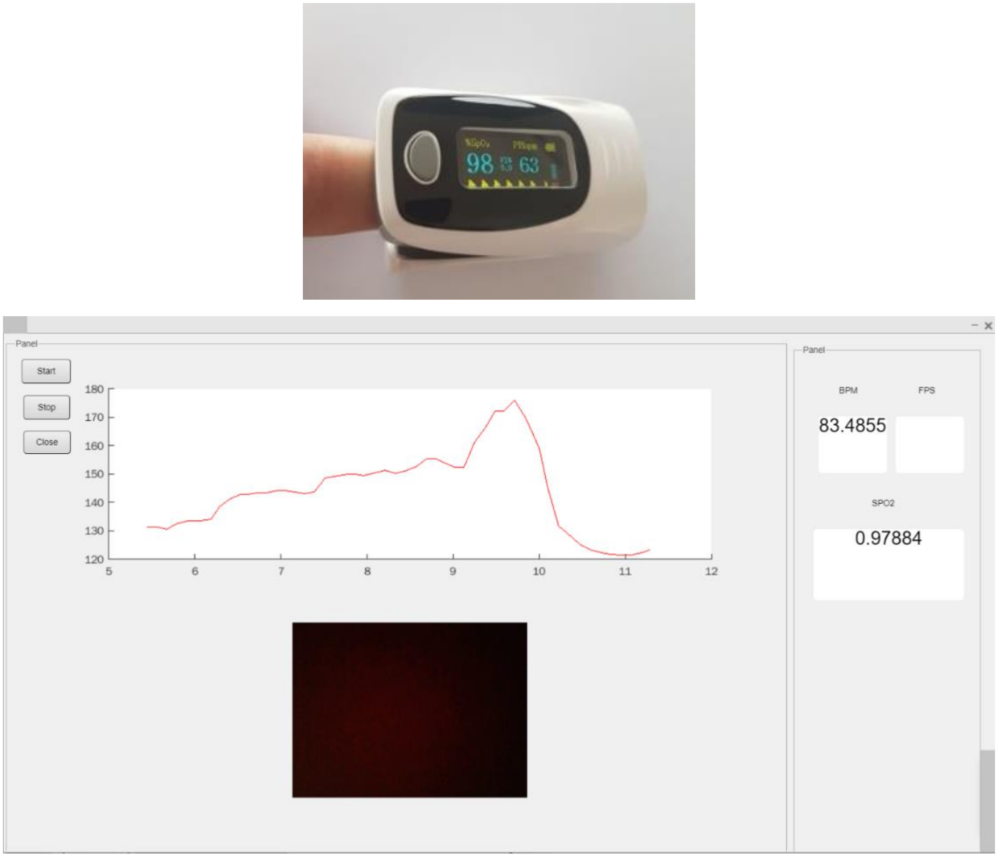


Figure 36. Obtaining the percentage of oxygen on the blood arteries.

The approach followed considered **#Hypothesis_2**.

3.9 Respiratory Frequency

The respiratory rate is the number of breaths per minute, that is, the number of times the combination of inspiration (entry of air into the lungs) and exhalation (exit of air from the lungs) occurs in one minute. The respiratory rate can be evaluated by counting only the number of inspirations per minute, by observing the chest expansion at each inspiration, that is, by counting how many times the chest goes up.

The respiratory rate can be obtained by counting the number of breaths during one minute, for a more accurate result your body should be at rest as in example, it is better measured if you are in a sitting position or laid down in bed. The breath rate can be obtained by counting the number of pikes, maximum in the heart rate, every time the heart rate gets a maximum means you have inhaled, showing the number of breaths per minute. On the plot it is possible to identify low frequency waveforms mixed with high frequency sawtooth (small spikes). Each small peak corresponds to a pulse beat (heartbeat). And the great peak-valley transition corresponds to the respiratory cycles.

The application was developed in Python and placed online via Flask, basis on the RGB values obtained by the camera and takes in consideration the maximums and the minimums of the cardiac frequency, counting the number of times it goes down (Figure 37) and also was used a second approach in a second application based on the calculation of motions and velocities.

The maximums of the cardiac frequency correspond to an inhale, the sum of maximums in one minute gives the breath rate. The value of the number of breathings per minute was calculated using the Python programming language and by counting the number of times the signal decreases, the application also has a graphic showing the breathing variation.

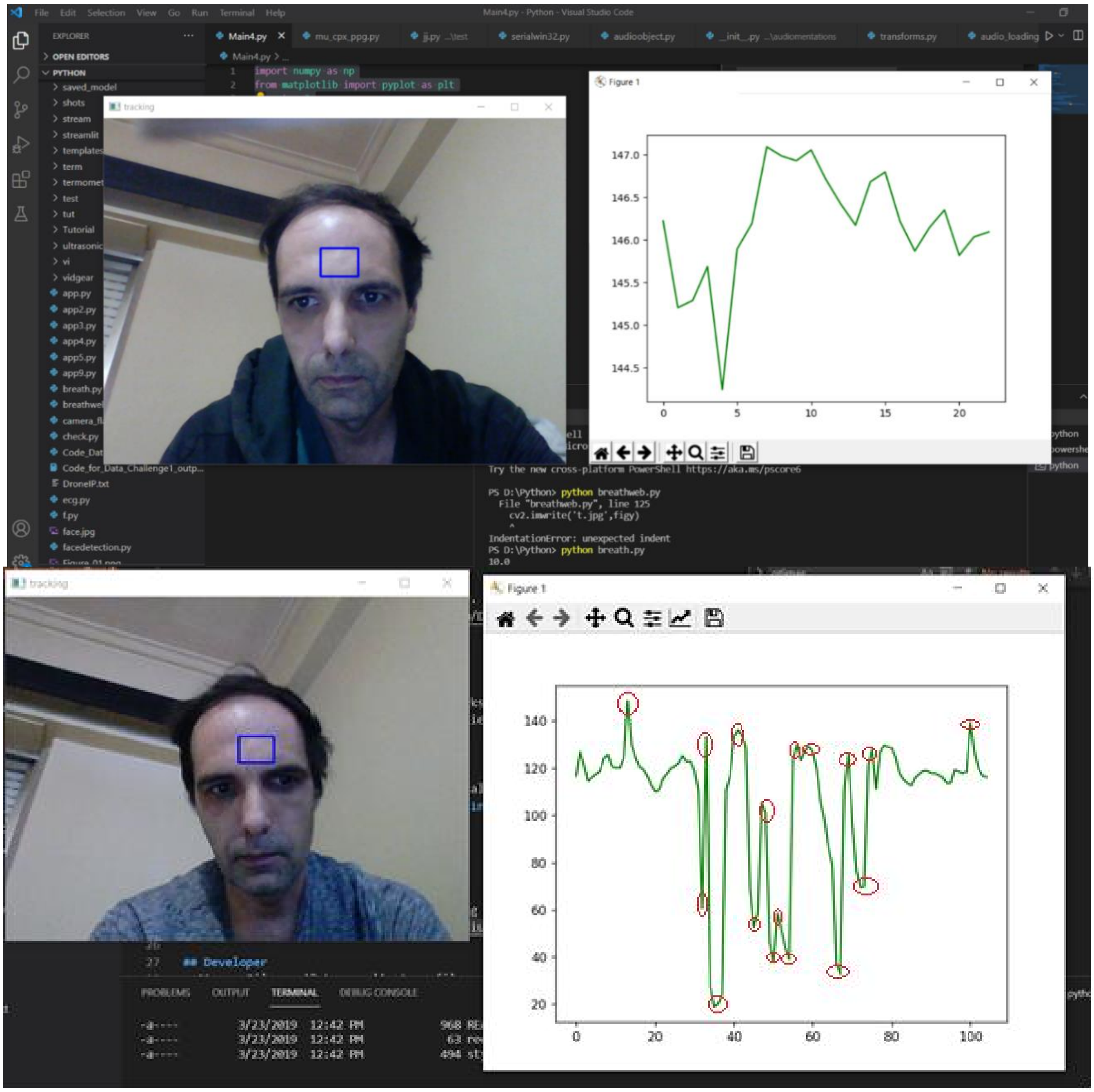


Figure 37. Breath rate detection and comparison in Python.

The reference values considered in the program for respiratory rate are: 12 to 18 breaths per minute. The developed prototype with Python and Flask allows in the final presented solution to obtain this value using the infra-red (IR) sensor which can be a web camera and the exact value of the number of breaths in one minute is stored on the MySQL database.

Another application (see Figure 38) was integrated in the web solution, based on the code [55] that takes in consideration motion and velocity.

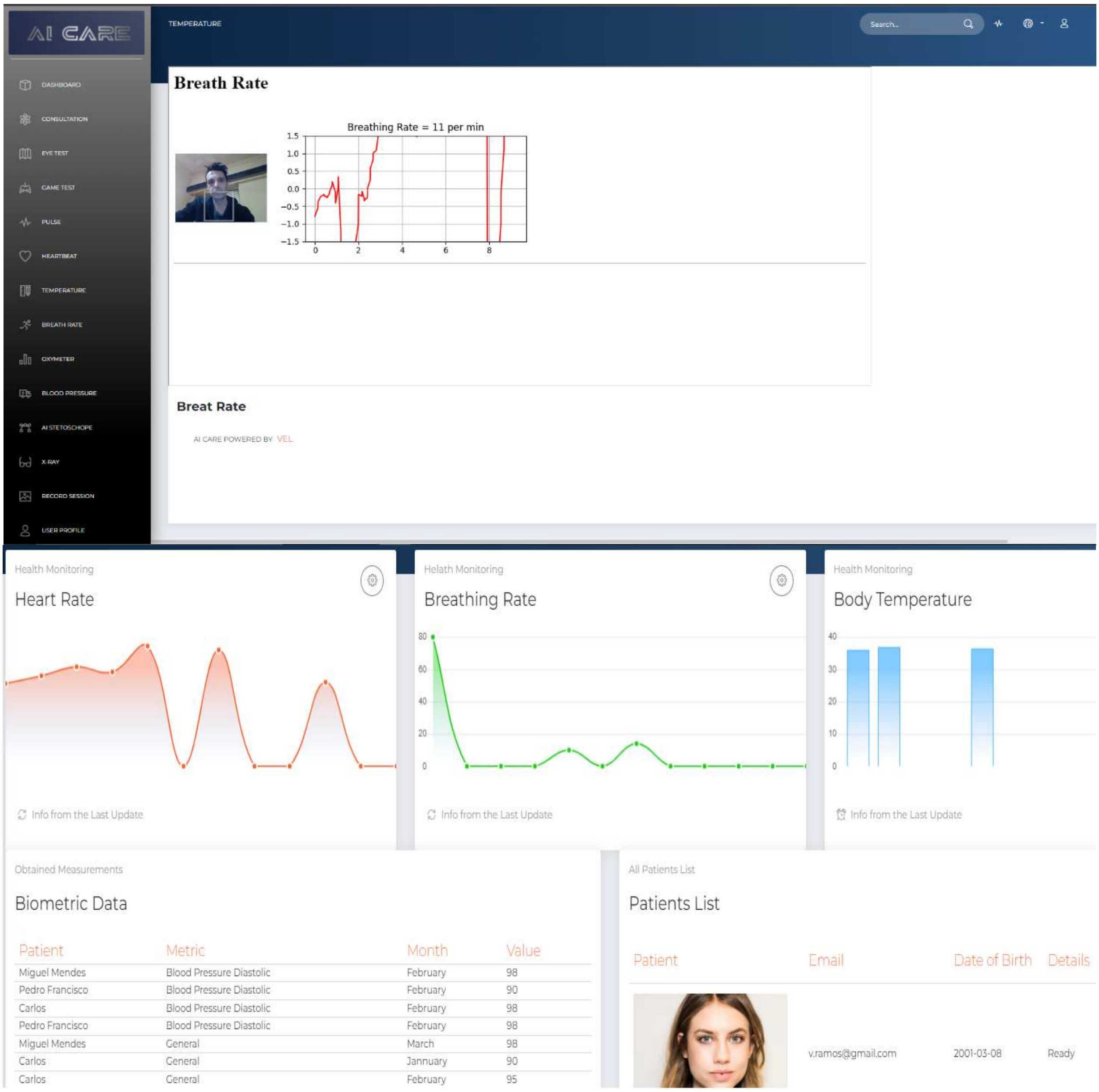


Figure 38. Obtaining the breath rate and adding to the clinical record of the patient. Adjusted from the code [55].

The approach followed considered **#Hypothesis_1** and **#Hypothesis_3**.

3.10 Secondary Care Perspective

On a perspective more focused in a certain pathology or organ, a prototype was developed showing a spectrogram of the values obtained by a stethoscope allowing to analyze the organs lung and heart and also a web uploader of medical images that mentions if the image in cause has a specific disease by comparing with datasets that have the disease and datasets that do not have the disease. For the image uploader were considered the disease covid-19 for thorax X-rays and CT scans and the disease brain tumor for MRI pictures of the head.

3.10.1 Analysis of Medical Images via a Convolutional Neural Network

An application using datasets of medical images (see Figure 39) was developed with the VGG architecture with 16 layers using Python, the TensorFlow software library and the Keras framework based on classification to identify in an image based on light gray scale the existence of possible diseases. In order to analyze X-Rays via web was used Flask, allowing physicians to upload the pictures and see if there is a possible disease on the uploaded image. For this application only the diseases covid-19 for chest X-rays and CT scans and brain tumor for MRI scans above thorax were considered.

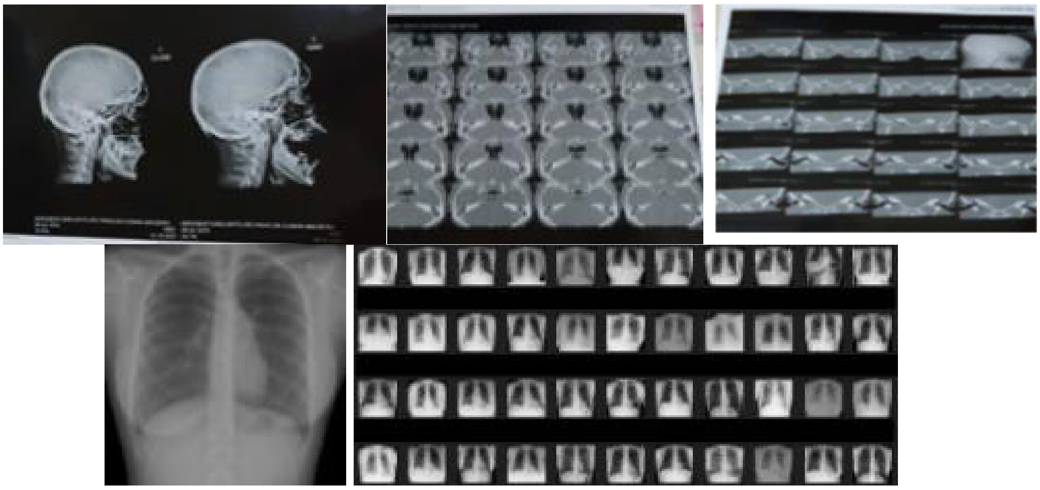


Figure 39. Obtaining the datasets for head and chest [60].

Via Python code, the classification process was implemented with the VGG-16 architecture, which uses convolution layers of 3x3 filter with a stride 1 and a layer of 2x2 filter of stride 2. The output uses a softmax, and the process is based on 16 layers with weights and has approximately 138 million parameters (see Figure 40).

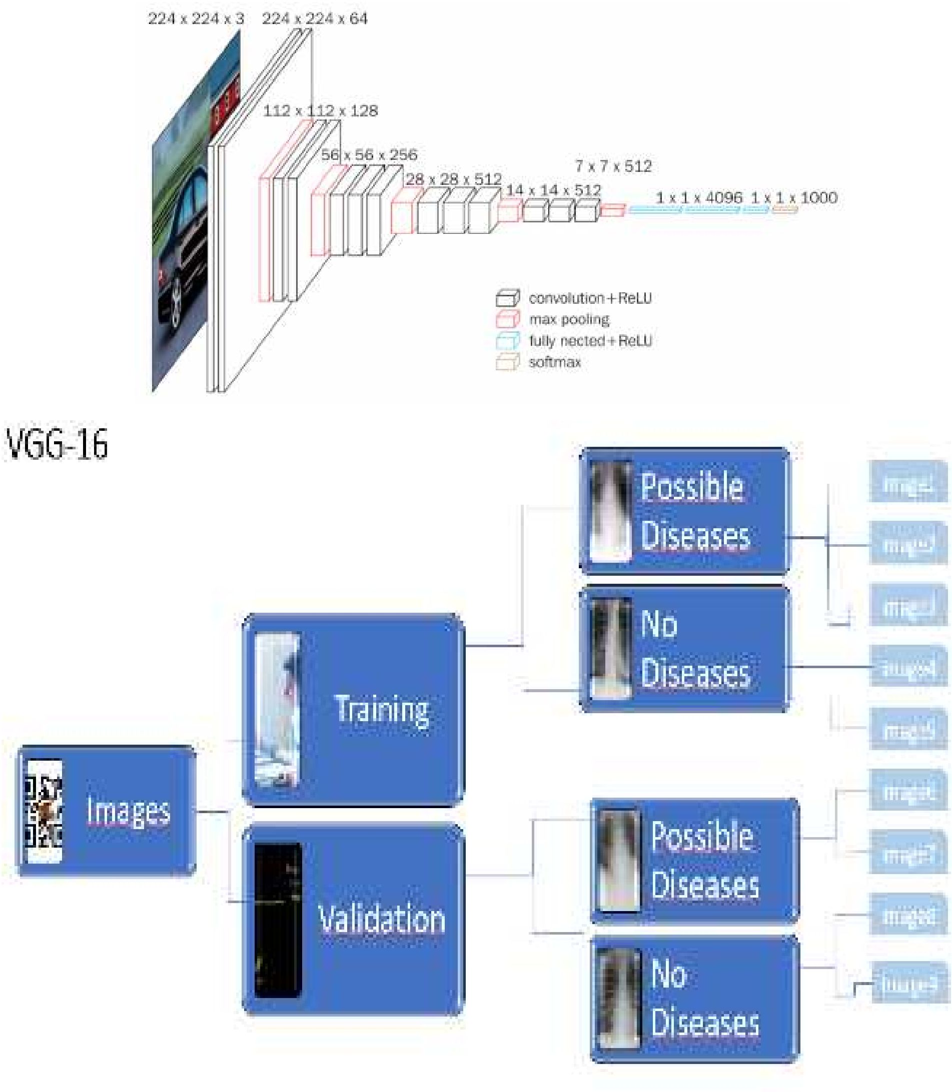


Figure 40. The VGG-16 architecture [59] and the process for datasets validation and training.

Finally, a general web application made mainly with JavaScript and PHP (see Figure 41) manages the process, allowing to combine the results obtained with the vital signs information and other medical data of the patient with the analysis done for medical images via Deep Learning for specific diseases.

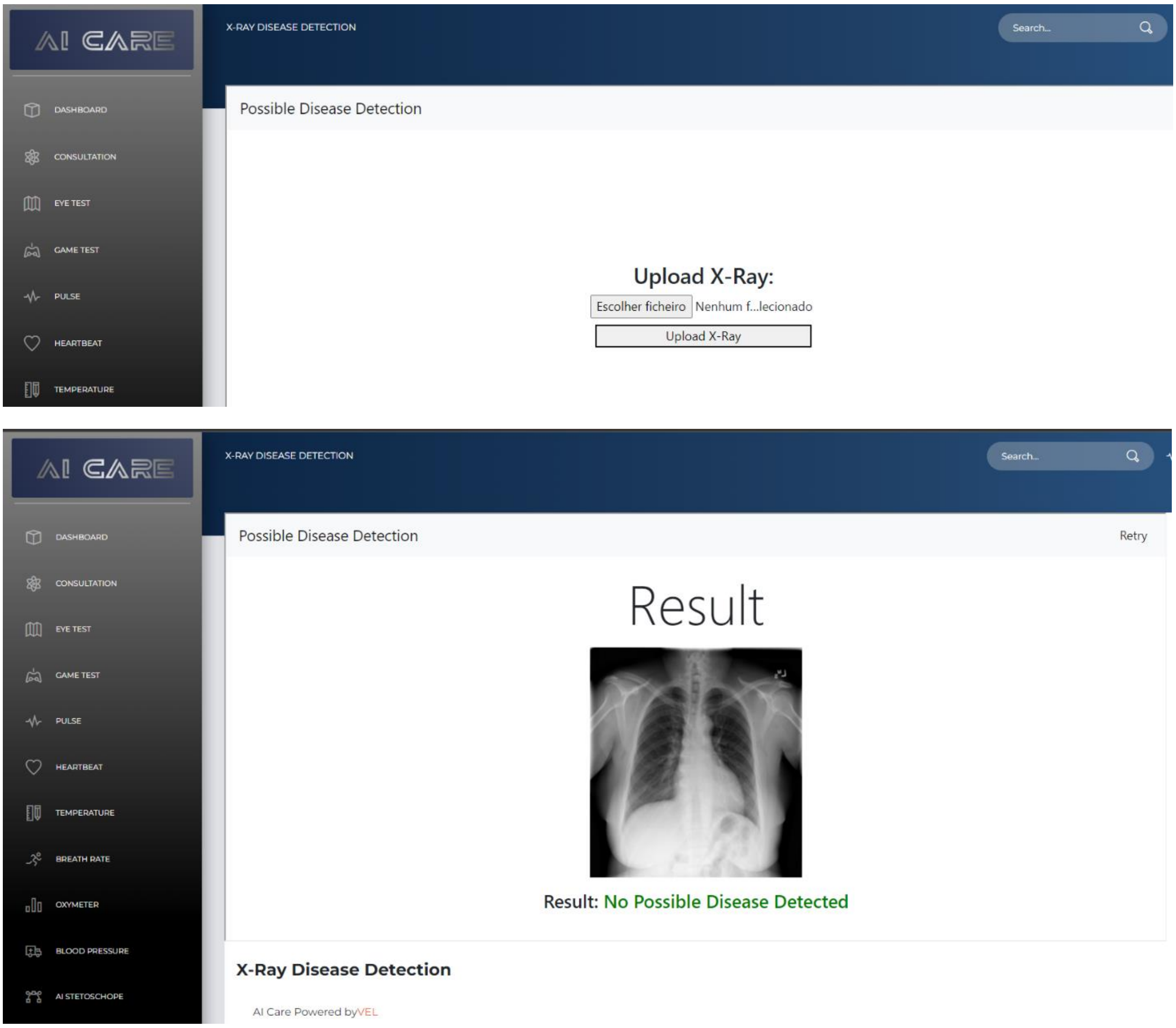


Figure 41. Usage of AI Care by uploading an image and showing the results (possible disease or no disease detected). Code adapted from [56].

The development was done considering **#Hypothesis_7**.

3.10.2 Showing the spectrogram of a Stethoscope

To help the physicians in analyzing the organs lungs and heart, a web application was developed mainly with Angular and TypeScript (see Figure 42) to obtain the spectrogram of the readings of a stethoscope, the process requires to connect a microphone to the cable of the medical device with contact (to avoid breaks in the passage of the sound) and with the computer via external line return (XLR) cable connection allowing the physician to check the signal strength or how loud is a signal over time at different frequencies represented in a waveform. The human ear can listen to frequencies between the 20 Hz to 20 kHz usually depending on the age.

The visualization of the spectrum of frequencies through time can help physicians in cases that they are not able to hear well or to facilitate the process of detecting an anomaly. Visual representation of sound frequencies can be used to better analyze the organs heart and lungs.

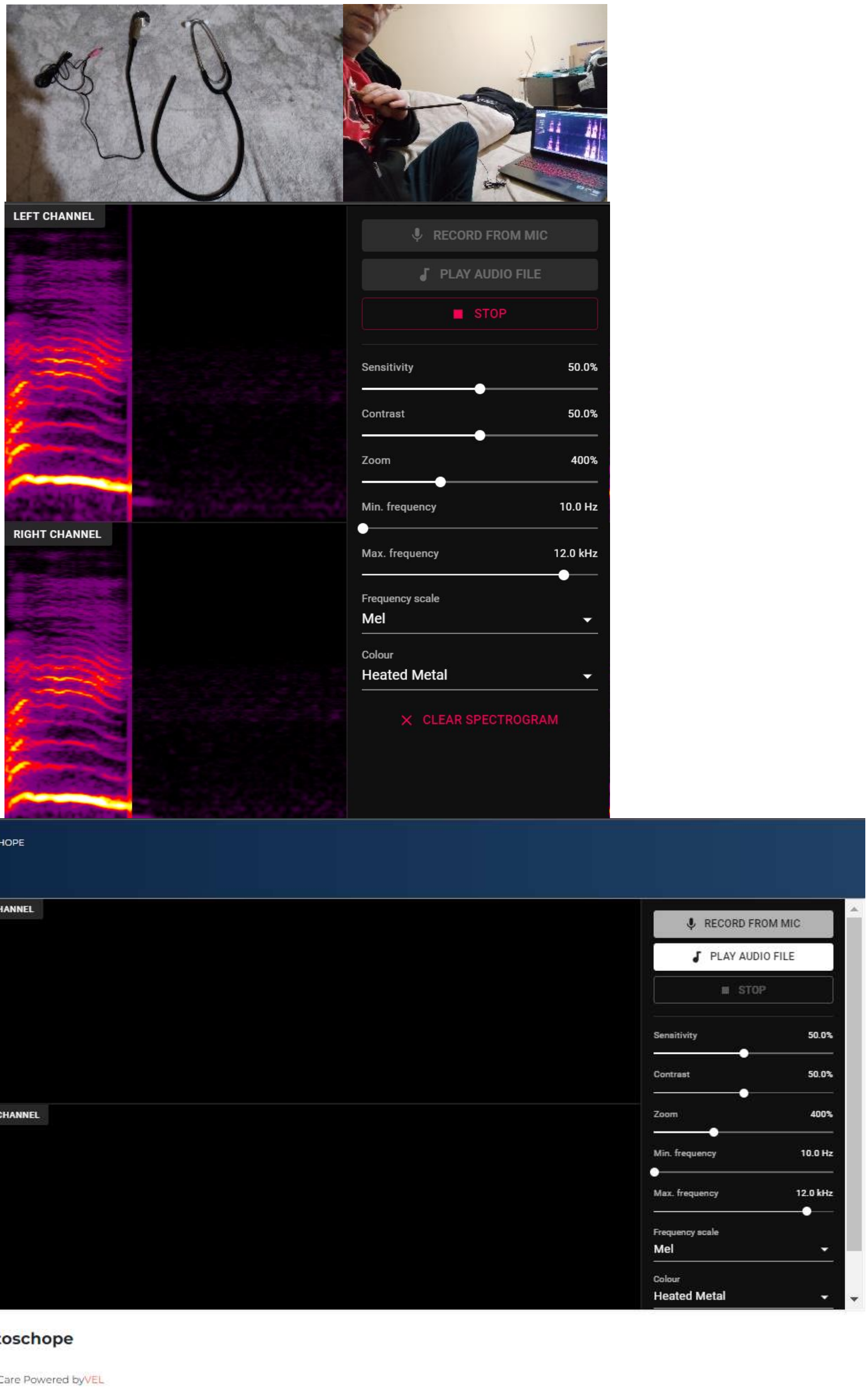


Figure 42. Use of a stethoscope and a microphone with XLR cable to connect the audio to the web application and demonstration via an online spectrogram. Adapted from the code [57].

This analysis takes in consideration **#Hypothesis_4**.

4. Test Analysis, Results and Validations

This section shows the results and tests made for the presented artifact based on a set of prototypes and processes, allowing to answer the research questions and achieve the objectives. The analysis shown on Table 2 is based on the results and specific hardware was required such as a stethoscope, a pulse blood pressure monitor, an oximeter, a smart watch, a camera, and an IR thermometer.

Table 2. Required material for testing purposes.

Hardwares used for testing		
Stethoscope and microphone 	ASUS-NotebookSKU. Model: GL552VW. Characteristics: Model: GL552VW. System SKU: ASUS-NotebookSKU. System Model: GL552VW. Processor: Intel(R) Core(TM). i7-6700HQ CPU @ 2.60GHz, 2592 Mhz, 4 Core(s), 8 Logical Processors. BIOS Version/Date: American Megatrends Inc. GL552VW.218, 3/16/2016. Display: NVIDIA GeForce GTX 960M. Adapter Descriptio NVIDIA GeForce GTX 960M. The graphical card allowed to improve the graphic quality of the games and videos produced. 	Samsung Galaxy S6 Edge +. Characteristics: Dimension. 70.1 x 142.1 x 7.0 mm (132 g). Camera. Rear : 16MP OIS (F1.9) Front : 5MP (F1.9). Display. 5.1" Quad HD Super AMOLED. 2560 x 1440 (577 ppi). AP. Exynos 7420 (64-bit, 14nm), Octa core (2.1GHz Quad + 1.5GHz Quad). OS. Android 5.0 (Lollipop). Network. LTE Cat.6. Memory. 3GB RAM (LPDDR4). Battery. 2600mAh. The IMU of this phone was used for tracking the user. 
Smart Band Mi 5. Large dynamic color-display. Dynamic display with more than 65 dial themes. Characteristics: 11 sports modes. Rowing machine, jump rope, yoga, elliptical. 50 m water resistance. All-new women's health tracking. 24-hour heart rate monitoring. 24-hour sleep monitoring. 14-day extra-long battery life. Magnetic charging. The USB allows a connection to the phone and obtain the user biometrics, allowing the implementation of the Electrocardiography process 	Innjoo Infrared Thermometer WK-168. Characteristics: Color: White. Automatically turns off. Temperature measurement range: 32 - 42.9 °C. Built-in display. Temperature measurement units: F and °C. Height: 136 mm. Width: 38 mm. Depth: 33 mm. Power supply 2 x AAA batteries. 	Pulse Blood Pressure Monitor with Large Screen BW 315 Medisana. Characteristics: Fully automatic blood pressure and pulse measurement on the wrist. XXL-display: easy to read the results with date and time. 1 x 60 memories. Automatic pressure preselection and deflation. Cuff size for wrist circumference 14 - 19,5 cm. With practical storage box. Requires Batteries. 
ChoiceMMed Finger Oximeter. Characteristics: Measures heart rate. Has a transport bag. Belt. Low energy consumption. Automatically turns off after 8 seconds. Runs on 2 AAA batteries. Dimensions: 5.8 x 3.2 x 3.4 cm. Weight: 50 g. 		

4.1 Performance Tests and Results of Obtaining Vital Signs

The tests were performed in an indoor environment with artificial and natural light, most of the readings were close to the ones detected with medical devices. Via OpenCV it is possible to measure the distance of the face from the camera during readings (see Figure 43).

The tests were performed to a group of 12 people, being six females and six males with ages between 20 and 80 being some of them healthcare professionals (see Table 3 and Table 4).

The standard deviation was calculated using the formula:

$$\sigma = \sqrt{\frac{\sum(x_i - \mu)^2}{N}} \tag{3}$$

Where u is the average and N the number of testers, which in this case is 12.

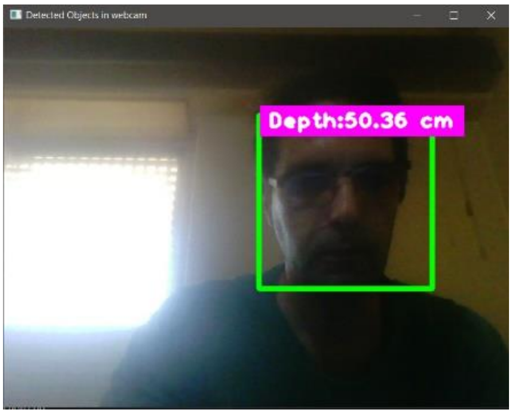


Figure 43. Using OpenCV to measure the distance of the face to the camera [58].

Table 3. Qualitative evaluation results (distance from camera, cms)

Testers	Distance from camera	Standard deviation
tester 1	70.6	9.516667
tester 2	71.2	10.11667
tester 3	52.4	8.68
tester 4	55.4	5.68
tester 5	52.4	8.68
tester 6	64	2.916667
tester 7	60	1.08
tester 8	53	8.08
tester 9	58	3.08
tester 10	68	6.916667
tester 11	65	3.916667
tester 12	63	1.916667
Average=	61.08333333	

Table 4. Quantitative evaluation results (time to completion in seconds)

Testers	Time taken	Standard deviation
tester 1	14	0.416667
tester 2	16	1.583333
tester 3	10	4.416667
tester 4	12	2.416667
tester 5	19	4.583333
tester 6	13	1.416667
tester 7	10	4.416667
tester 8	14	0.416667
tester 9	13	1.416667
tester 10	15	0.583333
tester 11	18	3.583333
tester 12	19	4.583333
Average=	14.41666667	

In order to check the accuracy results, tests were done between the values obtained by the web application and the values obtained by an oximeter, an Infra-red (IR) thermometer and a pulse blood pressure monitor. The test is based on monitoring the values of body temperature, blood pressure (considering the systolic and diastolic readings), cardiac frequency, oximetry and respiratory rate (Table 5). After getting the readings from the developed applications the values were compared with medical devices in order to determine the accuracy of the presented prototypes, the information obtained was stored in the database and it was noticed an high level of satisfaction from the users because for some cases the process of obtaining the values did not required many efforts like some traditional processes (see Figure 44).

Figure 44. Performing the tests with physicians.

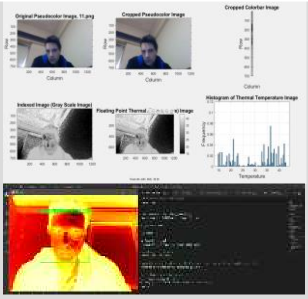
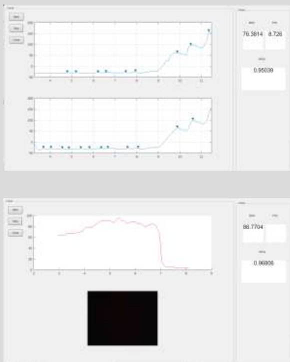
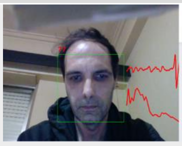
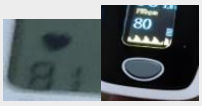
The accuracy was high for the cardiac frequency, breath rate and temperature. Concerning oximetry and blood pressure the values showed a lower accuracy as it was used an approach based on applying formulas to the RGB reading obtained by an IR camera.

For the oximetry, temperature, and blood pressure measurements the light level and noise still have impact and the system has to be calibrated to the level of lightning of the room where the analysis is performed. Table 5 compares the values obtained by the developed applications with the values measured with medical devices for the several vital signs, the general health status is placed by the healthcare professional after analyzing the data. Concerning oximetry and blood pressure some authors consider impossible to obtain these values using an IR camera, an attempt was done to read these vital signs but sometimes the values were outside the threshold making the results related to accuracy inconclusive. The accuracy was obtained via the formula:

$$x = \frac{AV*100}{MDV} \quad \text{or} \quad x = 100 - (\frac{AV*100}{MDV} - 100) \qquad (4)$$

Where AV corresponds to the values obtained by the application and MDV to the values obtained by the medical devices. For the general health status it is not possible to provide an accuracy level as this value is inserted manually by the physician after analyzing the data obtained.

Table 5. Analysis of participant number 1.

	Description	Values obtained by the AI web Application for tester 1	Values obtained by medical devices	Reference Values	Accuracy
Body Temperature	Body temperature refers to the production of heat in the body and the mechanisms for its regulation and maintenance, essential to maintain systemic homeostasis.	 36.6	36.2 	Body temperature: 35.5º to 37.5º Celsius	>94%
Blood Pressure	Blood pressure or blood tension is the force that the blood exerts on the walls of the arteries during its circulation	Systolic: 150 mmHg Diastolic: 89	 Systolic: 150 mmHg Diastolic: 89	Blood Pressure: Systolic: 90 to 140 mmHg Diastolic: 60 to 90 mmHg	Inconclusive
Oximetry	The Oximetry is a test that lets you know how much oxygen is being carried in the blood. The oxygen level measured with an oximeter is called the oxygen saturation level (SpO2).	 SpO2: 96%	 SpO2: 96%	Oximetry: oxygen saturation ≥ 95%.	Inconclusive
Cardiac Frequency	The cardiac frequency rate is the number of times your heart beats per minute.	 Heartbeat: 80	 Heartbeat: 80	Heart rate: 60 to 80 beats per minute.	>96%
Respiratory rate	The respiratory rate is the number of breaths per minute.	 12	12	Respiratory rate: 12 to 18 breaths per minute.	>90%
General Health Status	Value considered after the obtained vital signs readings	97	97	Percentage.	Not applicable

AI for computer vision nowadays allows to report vital signs values close to the ones obtained via medical devices; the image treatment process tends to open new trends in the future for healthcare. Concerning **#Research_Question_1** and **#Objective_1** was noticed a proximity of the results obtained by the developed applications with the values from the medical devices.

4.2 Tests and Results Concerning the Secondary Care Analysis Used

The binary classifiers for the medical images can be measured via several processes. The VGG-16 model was used with 16 layers and most of the datasets of images were obtained from the Kaggle database [60]. Although three cases were analyzed covid-19 for X-rays and CT scans and Brain tumor for MRI, this section shows the results for covid-19 detection in X-rays of the thorax analyzing the loss and accuracy obtained for the architecture used by epochs after the fitting process (see Figure 45).

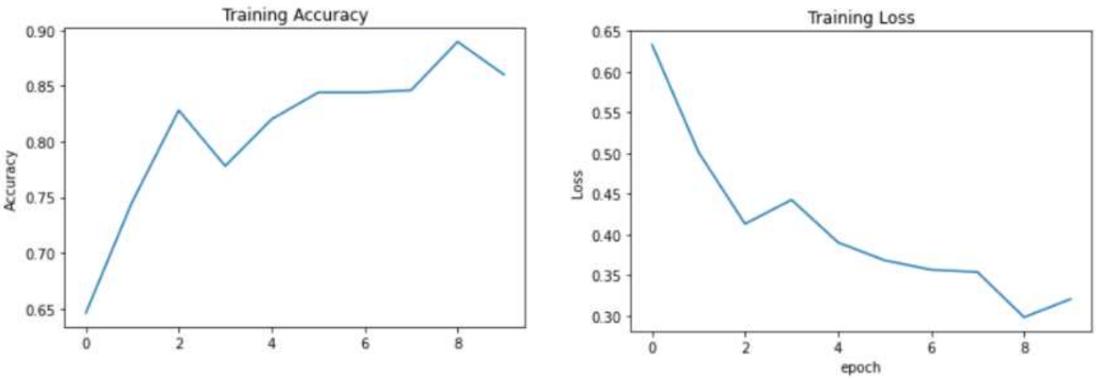


Figure 45. Accuracy and loss analysis for covid-19 detection in chest X-rays.

The training accuracy showed values above 80%. For the stethoscope, two different spectrograms were used, both by using free open-source code provided from the Massachusetts Institute of Technology that showed high sensitivity to variations of the sound (Figure 46).

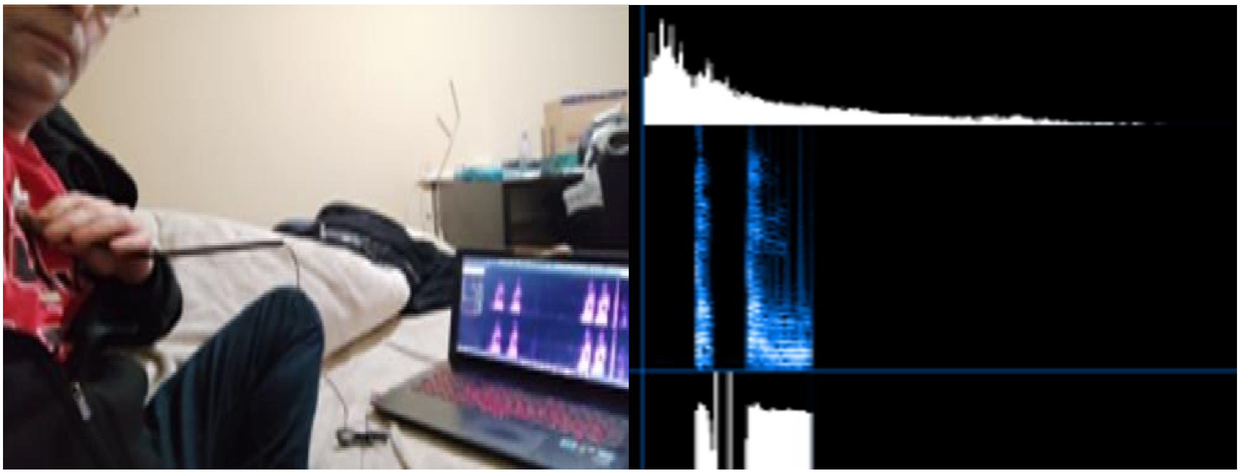
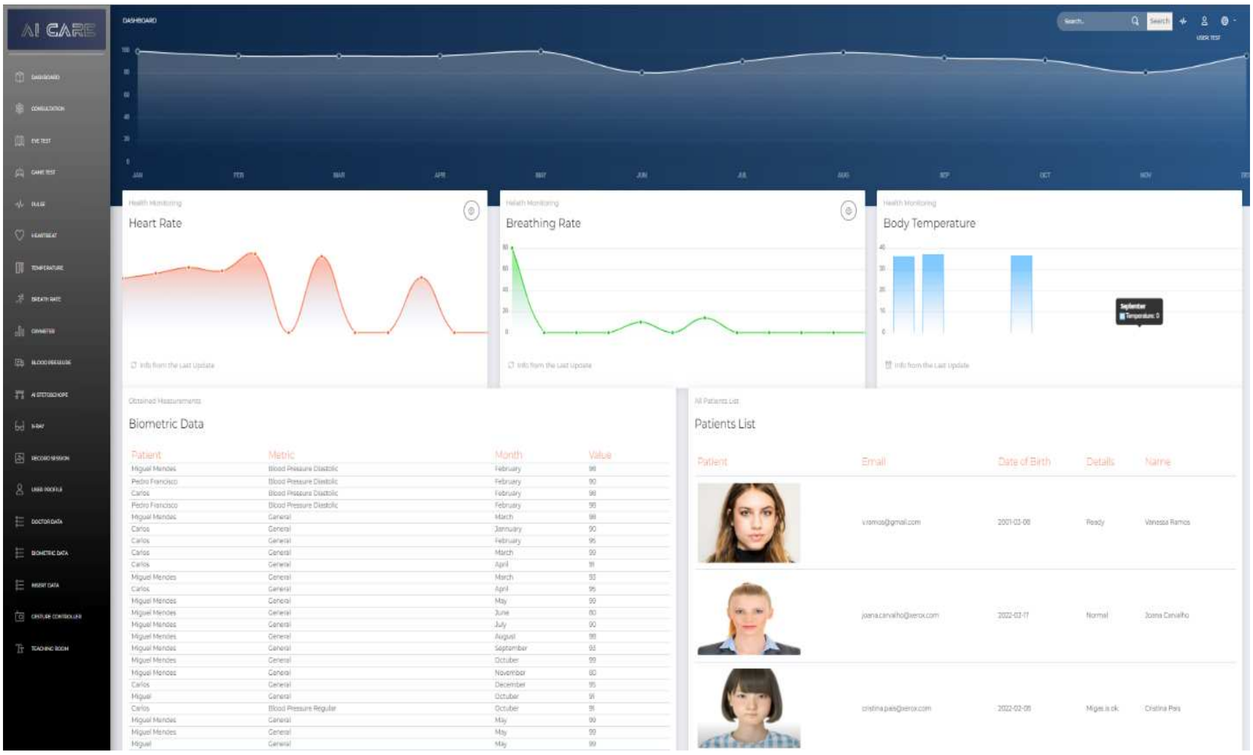


Figure 46. The two spectrograms used.

Concerning **#Objective_2** and **#Objective_4** and **#Research_question_2** and **#Research_Question_4**, the accuracy values obtained from tests of the artifacts developed were high.

4.3 Usability Tests

The **#Objective_3** and the **#Research_question_3** were analyzed by using software engineering practices and unit testing. A MySQL database and an application developed with different technologies such as PHP, JavaScript, Python, Flask among others was developed to store historical data. The values analyzed were based on the tests performed to a group of twelve people with ages between twenty and eighty, being half male and the other half female and some healthcare professionals. Most of the tests were performed indoors with natural and artificial light, some of the applications had to be calibrated in order to obtain the values (see Figure 47).



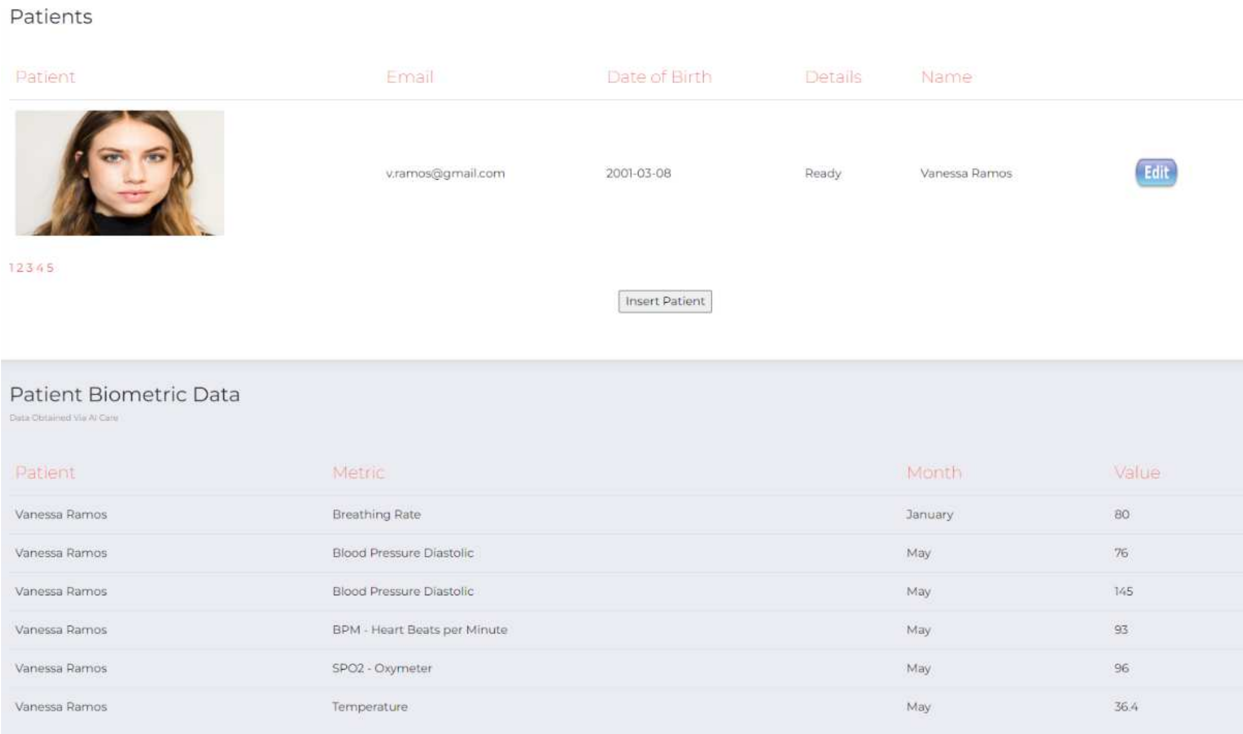


Figure 47. Storing the vital signs for different users concerning different time frames.

The usability dataset obtained took in consideration the following variables: time taken, emotions detected, areas more looked in the screen; clinic condition; sex; date of birth (age); address; family size; personal status; location; job; previous diseases; medication took; previous medication; previous medical operations; health status; cardiac frequency; blood pressure; systolic; diastolic; breath rate; oximetry; temperature; current symptoms; activities; nursery; genetic details; heritage and country (see Table 6 and Figure 48).

Table 6. Results of the readings from the testers.

Testers	Age (years)	Overall Health State (%)	BPM (number of beatings per minute)	Systolic (mmHg)	Diastolic (mmHg)	Oximetry (%)	Respiratory rate (number of breaths per minute)	Sex (male or female)	Time taken (seconds)	Emotions detected	Temperature (ºC)
tester 1	45	98	65	90	65	96	14	M	75	Happy	36
tester 2	48	97	68	103	72	99	12	F	40	Neutral	35
tester 3	34	99	73	94	76	96	16	M	45	Concentrated	37
tester 4	55	99	76	91	80	97	17	M	87	Neutral	37
tester 5	71	97	63	130	85	99	12	F	64	Neutral	35
tester 6	43	98	78	127	69	98	13	M	65	Happy	36
tester 7	69	97	64	110	87	95	16	F	55	Neutral	36
tester 8	60	99	61	94	71	96	15	F	76	Concentrated	35
tester 9	65	97	60	95	70	98	12	F	87	Happy	35
tester 10	55	98	76	91	80	97	17	M	87	Neutral	37
tester 11	48	97	68	103	72	99	12	F	40	Neutral	35
tester 12	71	95	63	130	85	99	12	F	64	Neutral	35

The analysis on the usability datasets was done to check the overall health state.

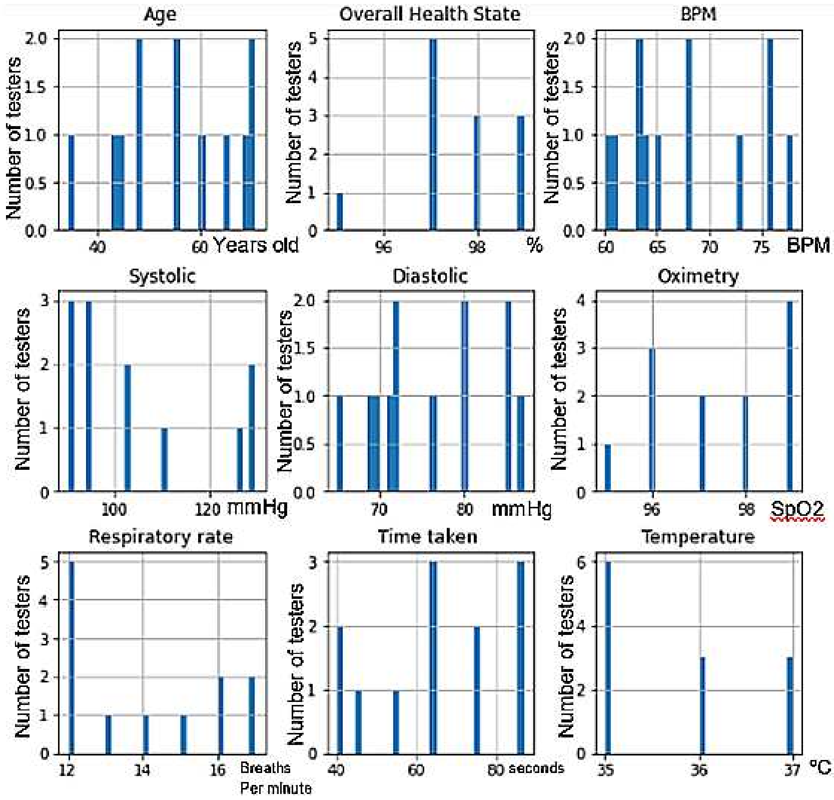


Figure 48. Results obtained from the testers.

The results (Table 7) showed values inside the threshold and was noticed that the heart beating per minute in adult women is higher than men and that people with younger ages have higher general health state results.

Table 7. Analysis of the results obtained from the testers from the usability dataset taking in consideration the mean, the standard deviation the minimum and the maximum.

	Age	Overall Health State	BPM	Systolic	Diastolic	Oximetry	Respiratory rate	Time taken	Temperature
count	12.000000	12.000000	12.000000	12.000000	12.000000	12.000000	12.000000	12.000000	12.000000
mean	55.333333	97.583333	67.916667	104.833333	76.000000	97.416667	14.000000	65.416667	35.750000
std	12.115605	1.164500	6.331140	15.741279	7.248824	1.443376	2.088932	17.640132	0.866025
min	34.000000	95.000000	60.000000	90.000000	65.000000	95.000000	12.000000	40.000000	35.000000
25%	47.250000	97.000000	63.000000	93.250000	70.750000	96.000000	12.000000	52.500000	35.000000
50%	55.000000	97.500000	66.500000	99.000000	74.000000	97.500000	13.500000	64.500000	35.500000
75%	66.000000	98.250000	73.750000	114.250000	81.250000	99.000000	16.000000	78.750000	36.250000
max	71.000000	99.000000	78.000000	130.000000	87.000000	99.000000	17.000000	87.000000	37.000000

Via Power business intelligence (BI) it is possible to display the results and use AI to verify which factors tend to decrease the overall general health status (Figure 49).

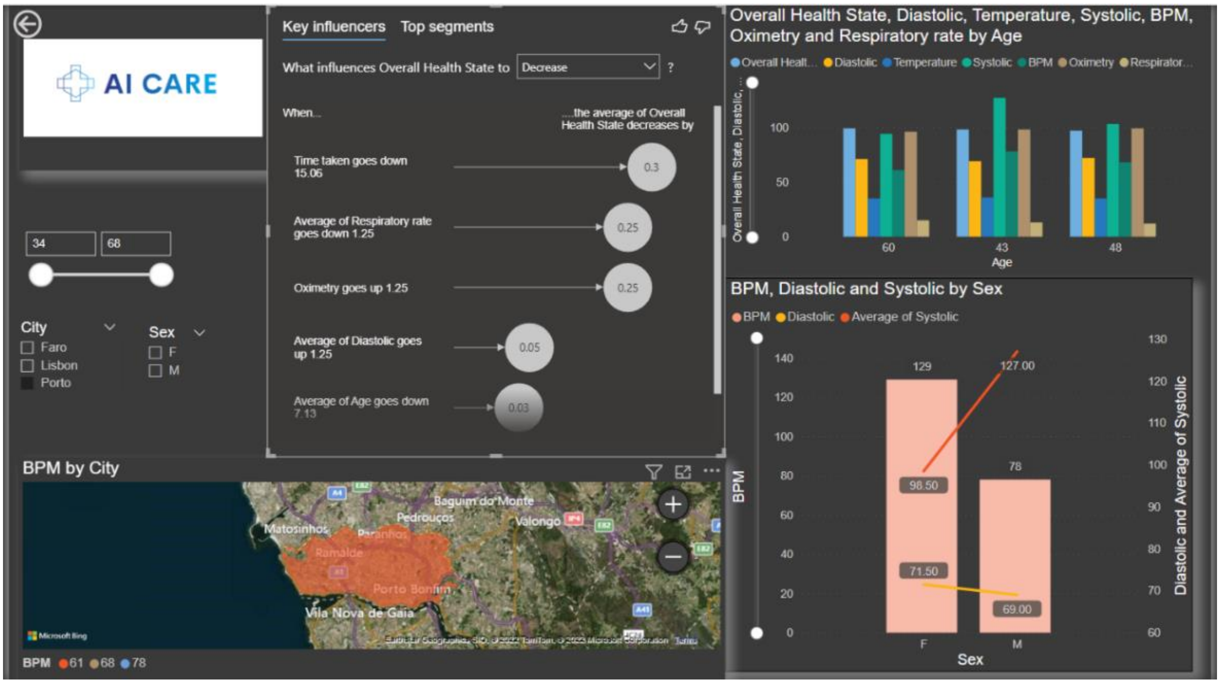


Figure 49. Reporting the results of the tests via Power BI.

Figure 49 reports the results of the tests via Power BI, searchable by years old, gender and location, uses AI to determine the factors that decrease the overall health state, presents the five vital signs by age, has a map showing the BPM results of the tests per location and the final plot shows the BPM, diastolic and systolic values per gender, demonstrating that adult women have higher BPM than men.

4.4 Analysis of the Results and Discussion

The tests performed allowed to retrieve conclusions, concerning the satisfaction, the results obtained were high when compared with traditional methods. From the several prototypes evaluated, it was noticed a preference for the reading of the cardiac frequency.

The study focused on different strategies using AI mechanics to perform medical activities taking in consideration the health status of the patients. Concerning the primary care approach was taken in consideration the process of obtaining vital signs using IR cameras being the accuracy high in some cases, the oximetry measurement is a complex process and the presented solution was based in a formula used by other researchers presenting a prototype as an approach for the problem, concerning the blood pressure traditional processes these require for some cases compression to facilitate the process of obtaining the pressure values, the presented prototype uses the phone camera and takes in consideration the RGB values of the ROI.

Via the tests, it was noticed that the objectives were achieved, most of the testers found that the applications developed achieved the objectives and that could be used for diverse medical situations. Concerning the secondary care analysis, the spectrogram of the values obtained by a stethoscope showed a high satisfaction for health care professionals, allowing to provide more information than just by hearing. The web uploader of medical images showed good accuracy and loss results for the three tested cases (thorax CT scans and X-rays for covid-19 detection and brain MRI for brain tumor detection).

For some of the applications during tests was noticed some difficulties in getting the readings because the web camera has to detect the body parts that is going to interact, requiring in most cases to correctly place the users, with a distance of around 70 centimeters from the sensor, if the necessary body parts are not detected the applications will not work. Most of the testers found that these types of applications with AI mechanisms will be used in the future. The results obtained allowed to perform an overall evaluation and appraise if the investigation objectives were achieved and answer the research questions.

An assessment was done on the presented solutions as a complementary process to the existing e-health applications. Most of the testers agreed that the implementation of AI mechanisms in software can provide more efficiency, control and functionality to the applications.

The problem of performing medical activities via web can be approached via different perspectives being the systems focused on using different processes like online consultations, image uploader for disease detection, use of spectrogram to analyze the stethoscope values and a process of obtaining the vital signs.

5. Conclusions, Limitations and Future Research

This dissertation proposes an innovative process of obtaining vital signs and detect diseases from medical images, improving the traditional processes of online consultations and diagnosis. The algorithms developed allow performing the desired functionalities and providing an innovative concept that can be helpful for contagious diseases or cases that require constant monitoring.

The development process was described, and tests were performed to validate the proposed solution. The research took in consideration several sources of information and many articles of other researchers. In some cases, it was possible to obtain a high accuracy between the values obtained by the algorithms and the values obtained by medical devices which for some cases was possible due to the use of mathematical calculations. The presented solution consists in an integrator of several systems that can complement traditional processes, some applications were developed from scratch and others like the breath rate detection, the blood pressure detector, the temperature detection, the image uploader and the spectrogram were based in changing the referenced open-source code placing online and add to the general program.

The work required extensive research and several processes were tested to achieve the desired results. An innovative approach was demonstrated that allows via camera to obtain the vital signs and also to analyze online medical images and visualize the spectrogram of a stethoscope connected to the computer. The proposed solution basis on a new concept of e-health systems that contrarily to traditional processes allows to obtain the vital signs in real time, allow the use of a web stethoscope and giving a prediction to the doctor about the existence of a specific disease after uploading a medical image.

5.1 Answers to the Research Questions

After the development and the tests was possible to retrieve conclusions, a set of applications was developed in order to achieve the objectives and provide an answer to the interrogations of the investigation.

Answers to the research questions:

#Research_Question_1: How can the vital signs be obtained from a camera capturing the face of the user and the thumb? The use of certain libraries like OpenCV or JavaScript specific libraries allow that a camera via AI mechanisms for computer vision after detecting the ROI and treating the signals obtained to provide the values of cardiac frequency, body temperature, oximetry, blood pressure and breath rate, which are important for a diagnosis or to determine the level of health state and severity of a patient. To answer this research question this investigation used a strategy of use of the green channel for heartbeat, breath rate and temperature detection and the red and blue channels for determining oximetry and blood pressure values.

#Research_Question_2: How can the sound obtained by a stethoscope appear in a web spectrogram? Certain Python libraries are able to detect sound and to display the respective spectrogram of the values obtained. The presented solution used a stethoscope with a microphone that connects to the computer showing the signal strength, or “loudness” of the signal over time.

#Research_Question_3: How can an application store historical data of the previous obtained information such as body temperature, blood pressure (systolic and diastolic), cardiac frequency, oximetry and respiratory rate? An application called AI Care was developed using several programming languages and the information of the readings was stored in a MySQL database. For this research was used a three-tier architecture with a MySQL database and application programming interfaces.

#Research_Question_4: How can a disease be detected in a medical image using Deep Learning? Via deep learning models it is possible to classify an uploaded medical image to predict the existence of a specific pathology, the research took in consideration the VGG-16 model and used the standard performance analysis metrics.

5.2 Limitations

Although the accuracy results of the readings of the vital signs were high, it is possible to be increased, many projects like smart watches among others have also shown satisfactory results and other approaches and research have been performed with considerable outcomes.

The level of lightning for some cases has to be adjusted, cases of very low lightning or nonexistence will not allow to obtain the readings, the distance to the IR camera may also impact the results, the sensor for some cases has to detect the ROI otherwise the application will not work.

The parameters that define a case as an emergency may vary due to age, if the patient had done physical activity recently or if he consumes certain medication or has specific diseases, for these cases the maximum and minimum limits may vary and the user should report this situation via video chat, otherwise some emergencies might not be detected or defined incorrectly.

Concerning the image uploader, deep learning still has many research challenges, this research aims to present a possible contribution of completing traditional processes by comparing an uploaded X-ray, CT scan or MRI scan with datasets that have the disease and that do not have, in order to make a prediction, mentioning if the disease is present and measuring the performance of the obtained results.

There are many studies in this area presenting good results when compared with traditional methods. False positive and true negative cases may occur, so the model was tested and hyperparameters were changed in order to increase the accuracy.

Spectrograms allow the access to a visual representation of the sound obtained helping healthcare professionals in several processes like diagnosis, but for some cases other processes may present better results like MRI scans, biopsies, X-rays or CT scans.

There were some accuracy limitations concerning the oximetry and the blood pressure, e.g., the developed applications sometimes did not report accurate values.

Although the presented solution shows a possible approach to the process of diagnosis and consultation for some diseases and some cases other strategies may need to be followed like medical scans, or biopsies or other diagnosis processes due to specifications of the medical condition of the patient.

5.3 Future Investigation

An application called AI Care was developed using several programming languages and the information of the readings was stored in a MySQL database.

Possible futuristic research are the use of deep learning for other diseases, add more functionalities to e-health application like combining data of certain symptoms showing to the doctor how those symptoms were treated by other doctors, as an example, which pills were administrated and correspondent dosage and time frames, use of ultrasounds for healing purposes among many other possibilities. This research aims to provide a contribution to the existing knowledge of e-health applications showing an innovative approach for online consultations and diagnosis.

Accurate readings of the vital signs are an important step in the general diagnosis process. Artificial intelligence offers an opportunity for improving online health systems and virtual consultations but has many limitations and sometimes does not classify accurately and has aspects to discover where this dissertation focuses with many research challenges.

The detection process of viral diseases is problematic as it is very labor-intensive, time-consuming [9] and depends on the speed of development of the virus [10]. In order to reduce human error, new artificial intelligence technologies can be more assertive, cheaper and efficient, despite having some limitations and can avoid mistakes done by physicians. This theme offers an area of study with many open aspects.

Deep Learning Models and Artificial Intelligence algorithms still have some limitations concerning the classification accuracy of an X-Ray [15] or a CT scan or an MRI scan.

Future applications of the image uploader can be the use of other models for image datasets (**#Hypothesis_8**) or using the same model and change the datasets for images of other diseases.

Some add-ons of the developed project that can be taken in consideration are the reduction of the risk of contagion for the physician, less expenses, takes less time, provides more mechanisms that can complement the existing ones and the possibility of reaching regions with more economical difficulties.

Artificial intelligence mechanisms are currently being used in different areas like healthcare, industry, economics among others with many research challenges, some medical activities can be automated reducing the human error and allowing to help healthcare professionals in their activities.

5.4 Final Remarks

The research work was done during the period from 2019 till 2022 in ISCTE taking in consideration artificial intelligence for computer vision [48] concepts and software engineering practices [49].

I have enjoyed developing this project, allowing to develop new systems and approaches for the processes of obtaining the vital signs online using a camera as a sensor and also for detecting diseases on medical images using deep learning techniques and defending an innovative concept of online web diagnosis and consultations adding new features when compared with traditional processes.

During this time, I have learned new programming languages like Python, improved my software engineering skills and also learned a new process of looking at a problem and finding ways of resolving it.

This thesis was completed with the writing of a scientific article in the conference International Symposium on Sensing and Instrumentation (ISSI) 2022 (Shanghai, China, from the 17th till the 18th of November 2022).

I am grateful for the support of my supervisor and the physicians that helped me in clarifying my doubts.

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