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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

Carlos Filipe Paiva da Cunha Macieira Antunes

Master in Computer Science

Supervisor:
Doctor Carlos Eduardo Dias Coutinho, Assistant Professor
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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 life; there are not enough words to describe his help and support especially 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 professors Carlos Coutinho and Leonel Morgado for giving me all the support and necessary guidance.

Thanks ISCTE, IST and UAb 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 analysis 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.

I see this dissertation as a first step on my personal war against cancer and hope my dedication and hard work will inspire others to pursuit the objective of preventing and eliminating one of the most deadly and horrible diseases I have ever seen.

The best thing you can do in life is to help others, specially 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-Health permitem aos médicos acesso a diferentes tipos de informações, como 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 detecção 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 pretende apresentar uma nova abordagem quando comparada com as plataformas tradicionais ao disponibilizar sinais vitais online em tempo real, acesso a um estetoscópio web, um uploader de imagens médicas que prevê se uma determinada doença está presente, através de métodos de aprendizagem profunda, bem como visualizar todos os dados históricos de um paciente.

A dissertação visa defender o conceito de consultas virtuais providenciando mais funcionalidades, complementar 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 câmera, esta metodologia requer que o utilizador esteja em estado de repouso para os parâmetros definidos, para o qual foi definida uma abordagem de obter relaxamento através de jogos web durante as leituras e testando diferentes tipos de interfaces.

Permitiu concluir-se que no futuro muitos processos médicos actuais provavelmente serão feitos online, sendo extremamente útil para doenças contagiosas ou casos que requerem acompanhamento constante.

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

# Abstract

Web-based e-Health applications have been developing throw time, nowadays these applications allow doctors to have access to different types of informations, like which medication the patient has been taking or to perform online consultations.

Internet systems for healthcare can be improved by using artificial mechanisms for the processes of disease detection and of obtaining biological data, allowing medical professionals to have more details, facilitating the diagnosis and the application of the correct treatment for a certain person.

The research work in cause aims to present an innovative approach when compared with traditional platforms by providing the vital signs online in real time, access to a web stethoscope and a medical image uploader allowing to make a prediction detection of the presence of a certain disease via deep learning methods and also the visualization of all historical data of a patient. The dissertation has the objective of defending the concept of online consultations providing more functionalities than traditional methods for the performance of a medical diagnosis using software engineering practices.

The process of obtaining vital signs was done via artificial intelligence for computer vision using a camera as sensor. The user must be at a rest state for the defined parameters, which can be achieved by playing web games during readings and different interfaces were tested. The performed work allowed to conclude that in the future many medical processes most likely will be done online being extremely helpful for 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

**AI** **A**rtificial **I**ntelligence.
**API** **A**pplication **P**rogramming **I**nterface.
**ARM** **A**zure **R**esource **M**anager.
**ARMA** **A**uto**r**egressive **m**oving **a**verage.
**AUC** **A**rea **u**nder the ROC **C**urve.
**BI** **B**usiness **I**ntelligence.
**BPM** **B**eatings **p**er **M**inute.
**CA** **C**ertification **A**uthority.
**CI** **C**ontinuous **I**ntegration.
**CPU** **C**entral **P**rocessing **U**nit.
**CT** **C**omputer **T**omography.
**CRUD** **C**reate **R**ead **U**pdate and **D**elete.
**CUDA** **C**ompute **U**nified **D**evice **A**rchitecture.
**DSR** **D**esign **S**cience **R**esearch.
**ESB** **E**nterprise **S**ervice **B**us.
**FN** **F**alse **N**egatives.
**FP** **F**alse **P**ositives.
**FR** **F**unctional **R**equirements.
**GPU** **G**raphics **P**rocessing **U**nit.
**GUI** **G**raphical **U**ser **I**nterface.
**HTML** **H**yper**t**ext **M**arkup **L**anguage.
**HTTP** **H**yper **T**ext **T**ransfer **P**rotocol.
**HTTPS** **H**yper **T**ext **T**ransfer **P**rotocol **S**ecure.
**IaaS** **I**nfrastructure **a**s **a** **S**ervice.
**IIS** **I**nternet **I**nformation **S**ervices.
**IDE** **I**ntegrated **D**evelopment **E**nvironment.
**IS** **I**nformation **S**ystem.
**JSON** **J**ava**S**cript **O**bject **N**otation.
**KNN** **K**-**n**earest **n**eighbors
**LMS** **L**east **M**ean **S**quares.
**ML** **M**achine **L**earning.
**MRI** **M**agnetic **R**esonance **I**maging
**MVC** **M**odel **V**iew **C**ontroller.
**NoSQL** **N**ot **o**nly **S**tructured **Q**uery **L**anguage.
**PaaS** **P**latform **a**s **a** **S**ervice.
**PID** **P**roportional **I**ntegra**l** **D**erivative.
**ROC** **R**eceiver **O**perating **C**haracteristic.
**ROI** **R**egion **o**f **I**nterest.
**Resnet** **Res**idual Neural **Net**work.
**REST** **R**epresentational **S**tate **T**ransfer.

**SaaS S**oftware **a**s **a S**ervice.
**SOA S**ervice-**O**riented **A**rchitecture.
**SOAP** Simple **O**bject **A**ccess **P**rotocol.
**SLR S**ystematic **L**iterature **R**eview.
**TCIA T**he **C**ancer **I**maging **A**rchive .
**TN T**rue **N**egatives.
**TP T**rue **P**ositives.
**UDDI U**niversal **D**escription, **D**iscovery, and **I**ntegration.
**UE4 U**nreal **E**ngine **4.**
**UI U**ser **I**nterface.
**UX U**ser **E**xperience.
**VGG V**isual **G**eometry **G**roup.
**WebGL W**eb **G**raphics **L**ibrary.
**WSDL W**eb **S**ervices **D**escription **L**anguage.
**XML** E**x**tensible **M**arkup **L**anguage.
**XRD X**-**r**ay **D**iffraction.
**XRF X**-**r**ay **F**luorescence.
**YOLO Y**ou **O**nly **L**ook **O**nce.

# Chapter 1 – Introduction

1

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

The chapter in cause introduces the reader to the work performed being divided in six sections. First, will mention the context and motivation, second will show a detailed definition of the problem. The objectives appear as third and the research questions at fourth. The final part will show the research methodologies used and an outline section where an explanation of the document structure is showed mentioning an overview of the upcoming chapters.

## 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 contagious diseases or treatment of chronic illness, there is a tendency to convert some hospital systems to a more ambulatory process [2].

The interaction between doctors, patients and prescriptions can be done online, being less time consuming and shortening distances allowing 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 the triage problem, mention if a certain case requires intensive medical care, monitor the response of a patient to therapy, determine the relative status of vital organs, such as the heart and the lungs, observe trends in the health status, establish 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 been showing high 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 doctor to diagnose the state of the heart and the lung [6], a spectrogram of the audio signals appearing via web on the screen for the doctor facilitates his 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

Online consultations do not provide enough information [7]; displaying to the doctor the vital signs [8] on real time via web, can improve the diagnosis process, identify possible diseases and determine the severity level.

The traditional process of diagnosis requires too much work, have high costs, are very time consuming and the human error can occur, although AI mechanisms still have some limitations, the accuracy and the performance can be increased at lower costs than the one performed by a human in a laboratory [9].

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 CNNs for CT scans, X-rays or MRI scans [11].

Medical images are difficult to analyze via human eye [12], a web uploader can provide a prediction of the existence of a possible disease with a high level of accuracy. This study took in consideration two possible diseases Covid-19 from X-rays and CT scans of the thorax [13] and brain tumor from MRI scans of the brain [14].

Checking the state of the lung or the heart via a stethoscope just by hearing [6] might induce to errors, solutions like presenting a spectrogram of the sound signals on the screen facilitates the work of the doctor in analyzing these organs, which can be done via web.

In order to identify which processes provide more accurate readings of the vital signs, different user interfaces of full stack applications were developed in order to determine the most efficient 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 labour 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, can avoid mistakes done by doctors. 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 a MRI scan.

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.

## 1.3 Objectives

This research aims to offer an innovative solution for e-Health systems when compared with traditional processes defending the theoretical concept of placing some medical activities on line and increasing the performance of online consultations [17] and prescriptions.

There is a need to improve medical systems [18], the proposed solution can be used as complementary to the current systems adding more functionalities to the web applications like reading the vital signs, uploading medical images of the head and thorax to predict brain tumor or Covid-19 [19] and a stethoscope that shows the spectrogram of audio signals, facilitating the work of the doctor in diagnosing, making prescriptions and determining the severity. Some future extensions of the work that can be considered are the possibility of reaching less developed regions, reducing the risk of contagium for the doctor, lower costs, takes lesser time and provides more mechanisms that can complement the existing ones.

The research objectives to add a new methodology to the process of interaction between the doctor 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 severity. The main objectives of the dissertation are:

- Determining an efficient interface for the patient to obtain the vital signs while in a relaxed state like the one provided during gameplay. (Objective 1).
- Increase the accuracy of the readings of the vital signs obtained via the treatment of the Photoplethysmography (PPG) signal obtained from a sensor like a camera. (Objective 2).
- 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 CNN composed by specific layers. (Objective 3).
- Show the spectrogram of the sound signals of a stethoscope, so the doctor can better identify the status of the organs heart and lung (Objective 4).
- 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 5).

## 1.4 Research Questions

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

- Which of these three types of user interfaces from full stack applications can make the process of obtaining vital signals during gameplay more efficient: Interface 1: Simple, just games; Interface 2: Games with a video chat to communicate with a healthcare professional; Interface 3: Games with motion controllers? (Research Question 1).
- How can the vital signs be obtained from a camera capturing the face of the user and the thumb? (Research Question 2).
- How can the disease Covid-19 be detected in an X-Ray or CT scan of the thorax and a brain tumor from a MRI scan of the brain using Deep Learning? (Research Question 3).
- How can the sound signal obtained by a stethoscope appear in a web spectrogram? (Research Question 4).
- How can an application be developed to 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 5).

Answering the questions will allow to achieve the proposed objectives, to answer some of the questions was required to research the work of other authors, develop applications and perform tests comparing the results with medical devices for some cases.

## 1.5 Research Methodologies

In this section will be described the main research processes used to elaborate this document, starting by the systematic literature review 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 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. Phase 2 (Conducting):

Documents that were not relevant after reading the abstract, or that were duplicated 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. 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.

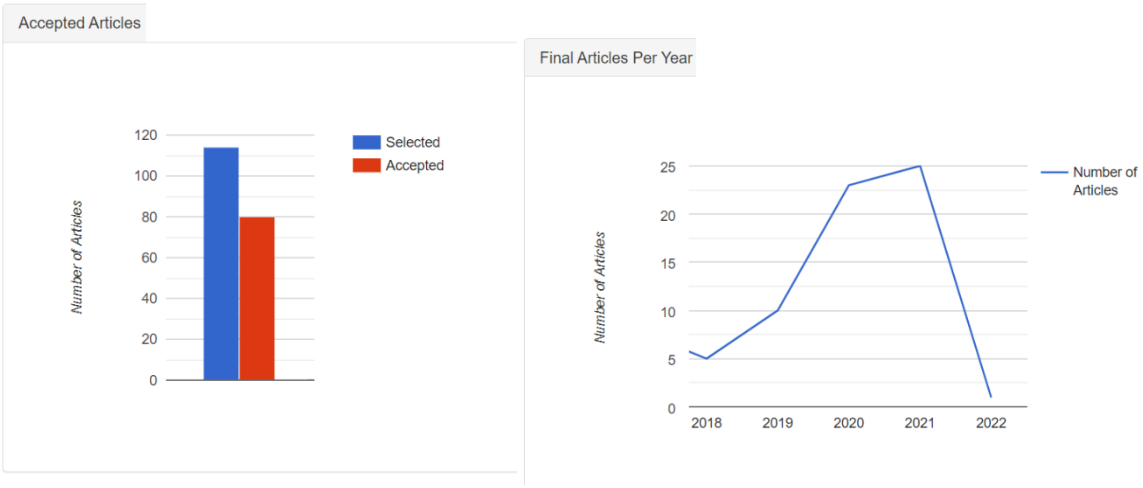



**Figure 1.** Selected studies and number of scientifical articles analyzed per year.

## 1.5.2 Design Science Research

For this research study it was used the design science research methodology 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 the iteration of the DSR because it will follow the continuous integration paradigm; in order to try to find the technical feasibility problems and present a solution.

Initially was defined the problem and after the objectives were defined for a possible solution, the third stage was based on developing the prototypes using several programming languages and platforms, and on the next stage the developed applications were used to try to solve the problem.

Concerning the evaluation several tests were performed and the communication was done via this dissertation.

**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 the 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 will be done and compared with the values of medical devices. Concerning the type of user interfaces for the patients tests will be performed, for the X-ray, CT scan and MRI scan uploader the accuracy and loss will be calculated and a confusion matrix used to measure the performance of the algorithm as well as the use of a Receiver Operating Characteristic (ROC) and also use of machine learning algorithms for predictions over the usability datasets. |
| ***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.<br>• 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. | It was used a Systematic Literature review 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 type 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 type of audiences. |

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.

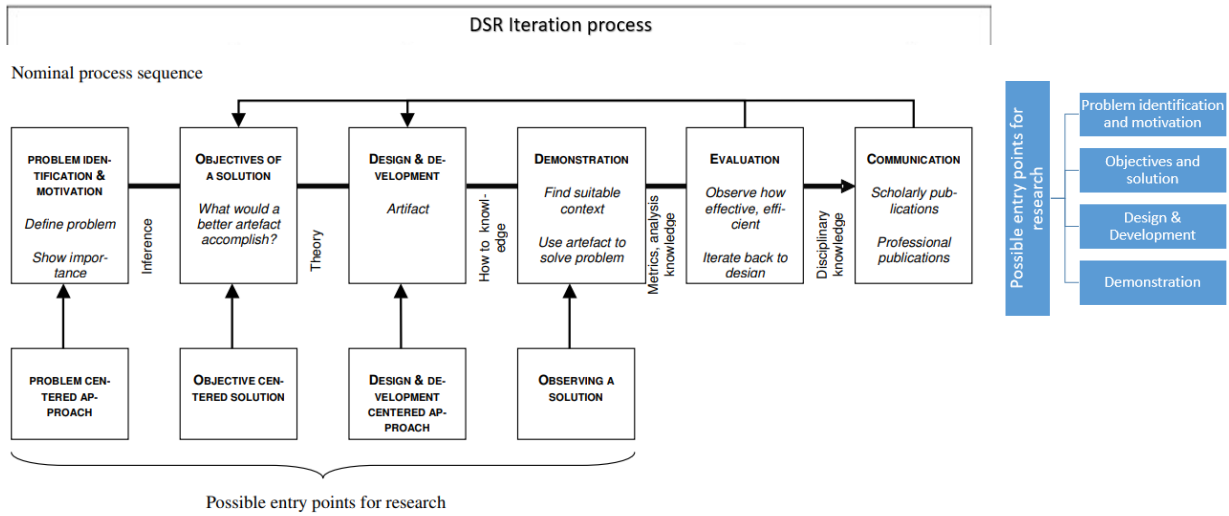



**Figure 2.** DSR model for this research, adapted from [24].

The knowledge base provides the raw materials through which the IS research is performed. This base is composed by fundaments and methodologies. 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.

## 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 mentioning also the objectives, challenges and research questions which this dissertation intends to answer followed by the research methodologies used, which in this case was a systematic literature review and the design science research methodology. The second chapter mentions the theoretical background which provides concepts and principles and also to prove the nature of the problem, as well as related work and investigations showing how other authors approached the problem. Chapter three show the development done having two sub sections, one more focused on the user interface of the full stack applications that are used by the patients and the second focused on the program used by the doctors that was separated due to clinical reasons in two divisions, being the first related to analysing the general state of health of the patient offering a primary care approach and the second more focused in organs and clinical specialities having a secondary care point of view.

On the fourth chapter shows the several tests and results obtained taking in consideration qualitative and quantitative aspects where the different interfaces to get the vital signs for the patients are compared to determine which is better to be displayed to the final user, another test performed was based in measuring the values of the vital signs obtained by the application and comparing with the values of the 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 deep model used based in the VGG-16 architecture was obtained for the gathered datasets and a confusion matrix was developed to determine the performance of the algorithm, also the ROC curve was implemented. As a last step a usability dataset was developed taking in consideration several variables allowing to obtain general patterns and make predictions using machine learning algorithms allowing to fundament the assumptions.

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

# Chapter 2 - Theoretical Background, Literature Review and Related Work

2

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 PPG signal and also for classifying diseases in X-Rays, CT scans and MRI scans, 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.

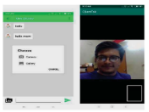


**Figure 3.** Video chat with the doctors [3].

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

## 2.2 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.

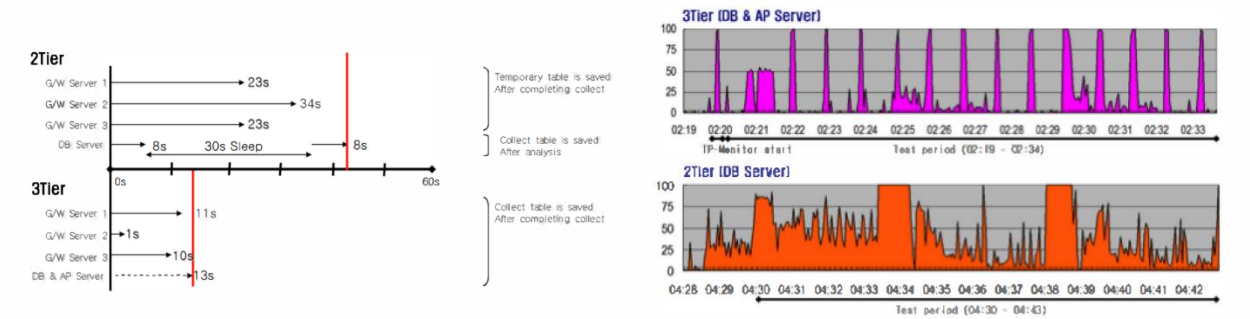



**Figure 4.** Examples of ping test and CPU usage between 2-tier and 3 tiers [26].

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 GUI (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 on the logic layer.

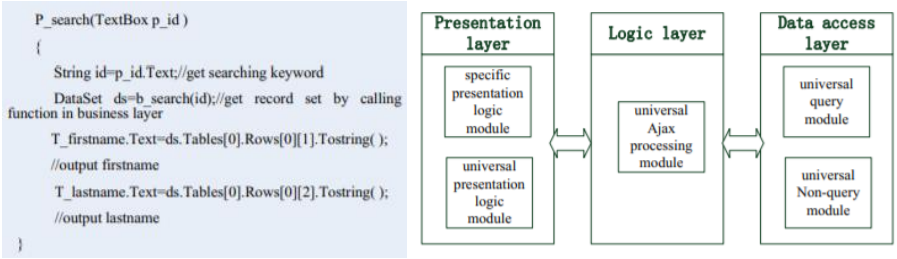



**Figure 5.** Presentation layer calls the function in the business logic layer [29].

## 2.3 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 API is a an application 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.

REST (REpresentational State Transfer) 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.

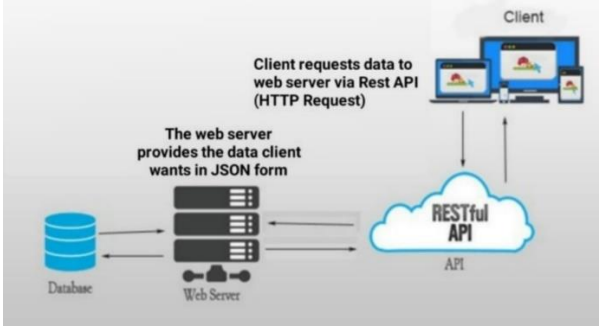



**Figure 6.** RESTful API interacting between client computer and database [31].

In the development process, the use of Web Services allow 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; 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 (HTTP or HTTPS) to interoperate, communicate, and exchange data messages, which have a standard visibility in Extensible Markup Language (XML) or JavaScript Object Notation (JSON), among others over the Internet. They can be tested using specific programs like Postman, Swagger and SoapUI Pro. During development the Hypertext Transfer Protocol (HTTP) 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.

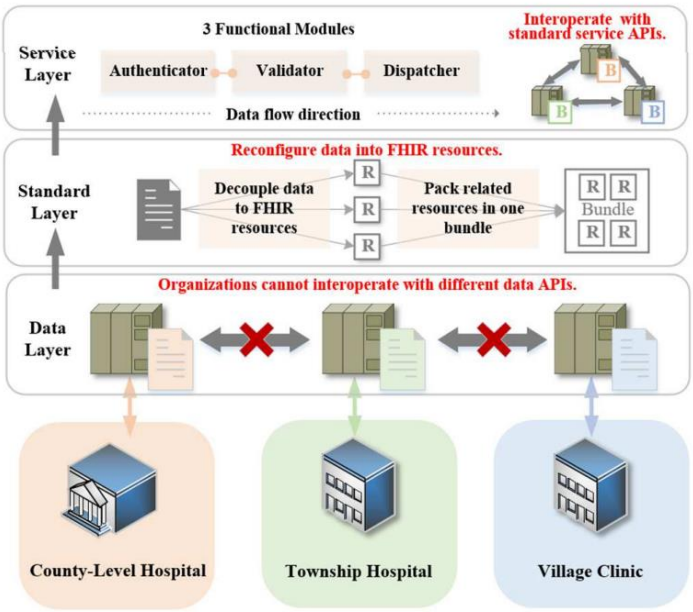



**Figure 7.** Logical architecture with Tiers and APIs. [33].

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.

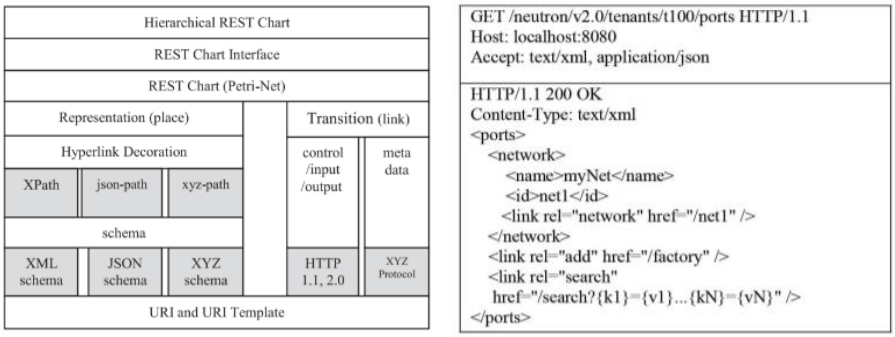
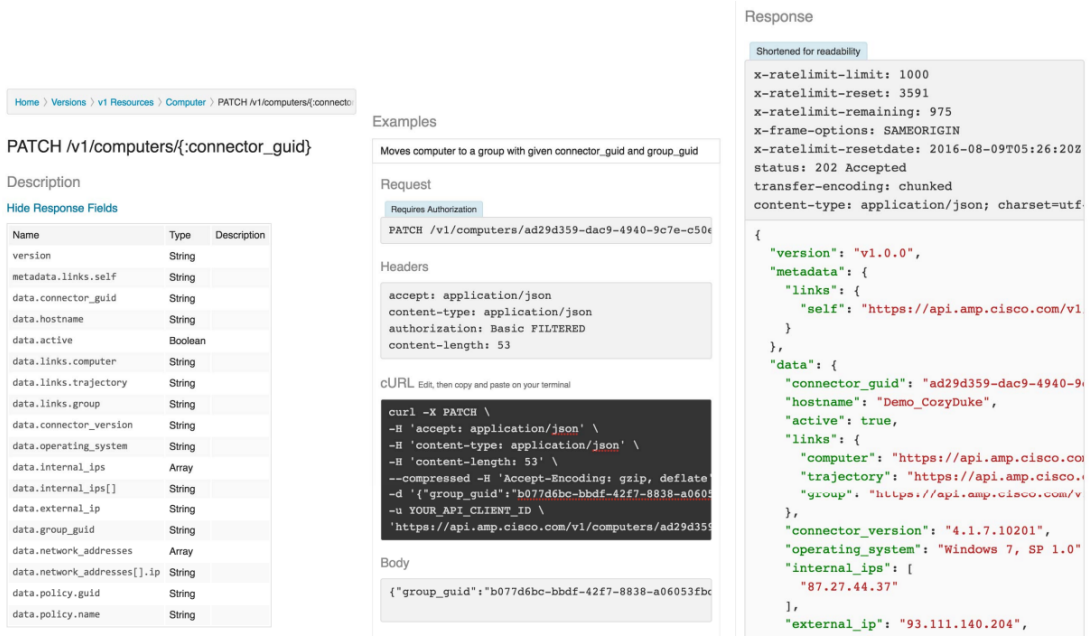



**Figure 8.** Modular architecture of REST chart, and a Get example [34].

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.




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

**Figure 9.** Example of the REST API documentation from Cisco using SpyREST [36].

## 2.4 Web Development

In web development, it is common to use databases and APIs, the browser has to be able to open the page and process the information. HTML can combine with CSS to make the page layout and esthetical aspects among JavaScript or Angular for functionalities.

Nowadays web applications use Web services to communicate with parts of the application or other applications. On the HTML code, there are several inputs or tags that allow to use the forms that were used in this project. The application can be divided in 3 tiers, and the data layer makes the interface with the database. According with the study of Haris [37] it is pointed out that PHP is the programming language more used. The research also mentions the several

advantages of the MVC architecture like security. The process of comparing frameworks is not easy and several criterias should be taken in account like debugging, how it connects with the database among many other factors. Many technologies can be used in web development like .NET, Java Spring MVC, on the frontend it can be used Angular. It is important to choose a technology, .NET has several particularities. Concerning web development, the servers should be configured according with the type of application that is going to be implemented. PHP appeared in 1995 by Rasmus Lerdorf, a technology that has been used in large scale, especially on the backend side.

| Occurances of patterns: | Sub-system 1 | Sub-system 2 | Sub-system 3 | Sub-system 4 | Sub-system 5 | Sub-system 6 | Sub-system 7 |
|---|---|---|---|---|---|---|---|
| Files with code duplication (over 30 lines) | 3 | 1 | - | 7 | 2 | 3 | 8 |
| Data injection | 86 | 4 | 1 | - | - | - | - |
| Thread and synchronization issues | - | - | 6 | - | - | - | - |
| Cross site scripting | - | - | 3 | - | - | - | - |
| Usage of resource after it was closed | - | 2 | 1 | - | - | - | - |
| Code that is likely to cause NullPointerException | 5 | 2 | 2 | 3 | 2 | - | 20 |
| Calling methods of immutable objects without using the result | 10 | - | - | 2 | 1 | - | - |
| Not closing resources | - | 7 | 2 | 2 | 2 | 4 | 190 |

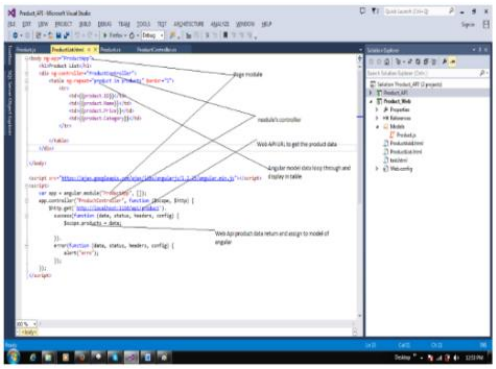


**Figure 10.** MVC application with frontend, backend and data layer in C# and code metrics [38].

Haralambiev [38] mentions that some metrics that can be used for code performance are: Files with code duplication (over 30 lines), data injection, thread and synchronization, cross site scripting, usage of resource after it was closed, code that is likely to cause NullPointerException, calling methods of immutable objects without using the result and not closing resources.

On the controller can be defined several operations like, associating the http command to a certain operation, such as the Create Read Update and Delete (CRUD) functions, or the details of the created entities. Microsoft has the Entity Framework and the ADO.NET, which helps with the development process.

Node.JS can be used in several platforms being a runtime environment that allows to use JavaScript and has an API for Input and Output (IO) operations, Chitra [39] compared the IIS with the Node.js in terms of performance and concluded that Node.js might be more appropriate for IO systems and not for applications that require high CPU usage.

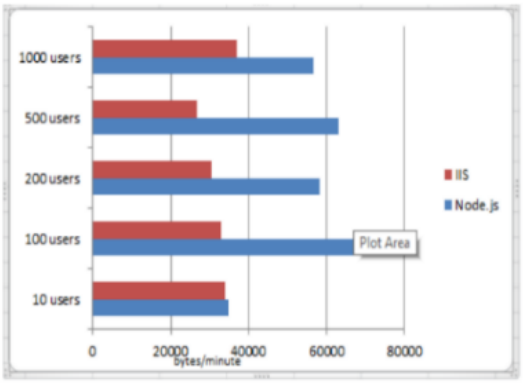
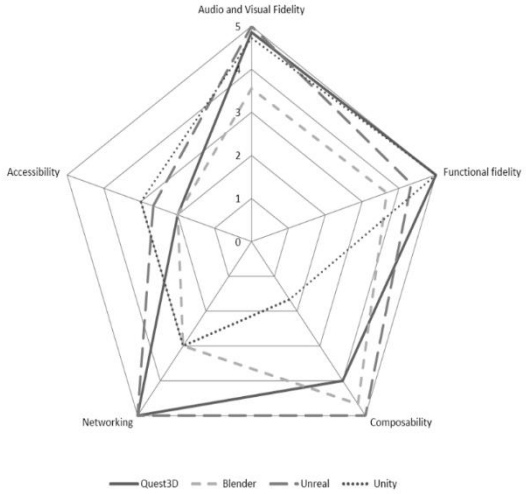



**Figure 11.** Speed performance comparison between Node.js and IIS. [39].

When a HTTP request arrives for a resource in the server, the HTTP.sys will ask the Windows Activation Service information from the configuration store (applicationHost.config) and details will be provided like the application pool and site configuration, the World Wide Web Publishing Service will use this information to configure the HTTP.sys. The Windows Activation Service will start a worker process for the pool in cause and returns a response to the HTTP.sys.

## 2.5 Development of Online Games

Game engines include modules of design, test, simulation, input (Keyboard, mouse) and output (3D rendering, sound). When building a game some criterias should be taken in consideration like the hardware requirements, the multiplayer support and the graphic quality. According with the work of Fritsch [40] many research was done in creating map textures and differentiating the indoor environments from the outdoor environments. The study of Petridis [41] compares engines with the criterias: 2D/3D support, deployment platforms, development platforms, graphics rendering, artificial intelligence, audio/visual fidelity, physics, networking, world (Level) editor, content creation, accessibility, composability, learning curve, scripting languages and licensing costs.




| | | *Quest3D* | *Blender* | *Unreal* | *Unity* |
|---|---|---|---|---|---|
| ***Scripting*** | Script | Yes | Yes | Yes | Yes |
| | Object Model | Yes | No | No | No |
| ***Supported AI Techniques*** | Collision Detection | Yes | Yes | Yes | Yes |
| | Path Finding | Yes | No | Yes | Yes |
| | Decision Making | Yes | No | Yes | Yes |
| ***Physics*** | Basic Physics | Yes | Yes | Yes | Yes |

**Figure 12.** Game Engines comparison, adapted from [41].

The CryEngine has many features like the flow graph, integration with 3D Max, a modelling tool that allows rigging, and a high graphic quality module that allows games to look more realistic. This engine also allows to develop multi threads and the use of several programming languages like LUA, ActionScript, C++ and has a world editor of very high capacity. Also allows changing the type of illumination and offers a high variety of shaders. Has a module that allows creating animations, another module to place sounds in certain regions of the map, provides the option for multiplayers, uses several types of image compression, offers many libraries and provides assets like the Game SDK that facilitates the use of this engine.

Unreal Engine uses DirectX9, has a store where several objects can be downloaded; belongs to Epic Games and has a very famous world editor used for architectural projects also. One of the most important components is the blueprint virtual scripting that lets managing many game components like the artificial intelligence without being hard coded, has a very high graphic quality, allows to export to several platforms like mobile and has an advanced lightning system [42]. Many famous games were built with this engine. Unreal Engine 5 has a vast amount of texture treatments and can be used for character and animation creation. This engine can be combined with other softwares like Maya, for importing several type of files and models; Unreal Engine is an update of the previous version named Unreal Development Kit (UDK). Supports C++ and has an integration with Visual Studio.

Unity engine allows the importation of several type of files and has an asset store with many open source projects and an Integrated Development Environment (IDE) called MonoDevelop, the compiler and export system is compatible with many platforms like iOS, PlayStation, Xbox, Linux, among many others.

**Table 2.** Game engines comparison.

| | *Unity 5.5.2* | *Unreal 4.15* | *CryEngine* |
|---|---|---|---|
| *Available programming language* | C# | C++, Blueprint | C++, Flash, Action Script, Luas |
| *Visual scripting system* | No visual scripting system | Blueprint visual scripting system | Flowgraph visual scripting system |
| *Licenses* | Free | Free | Free |
| *CPU Requirement* | 1 GHz or faster | Quad-core Intel or AMD, 2.5 GHz or faster | Quad-core Intel or AMD, 2.5 GHz or faster |
| *Dev OS* | macOS, Windows | macOS, Windows, Linux | Windows |
| *Graphic Card* | Graphic cards with Direct X9+ | Direct 11, OpenGL 4.1 | NVIDIA GEForce 470 GTX |
| *RAM* | 2 Gb RAM | 8 GB RAM (16 GB RAM) | 8 GB RAM (16 GB RAM) |

The Graphics Processing Unit (GPU) is an electronic circuit, which the performance can be increased by running thousands of threads in parallel [43]. The usage of an appropriate architecture and several GPUs at the same time can improve the performance, which can be done via cloud systems like Azure that has the Multi-GPU option and the NC T4_v3-series that allows to make GPU applications faster. The NVidia CUDA lets the usage of virtual instructions and parallel computing.

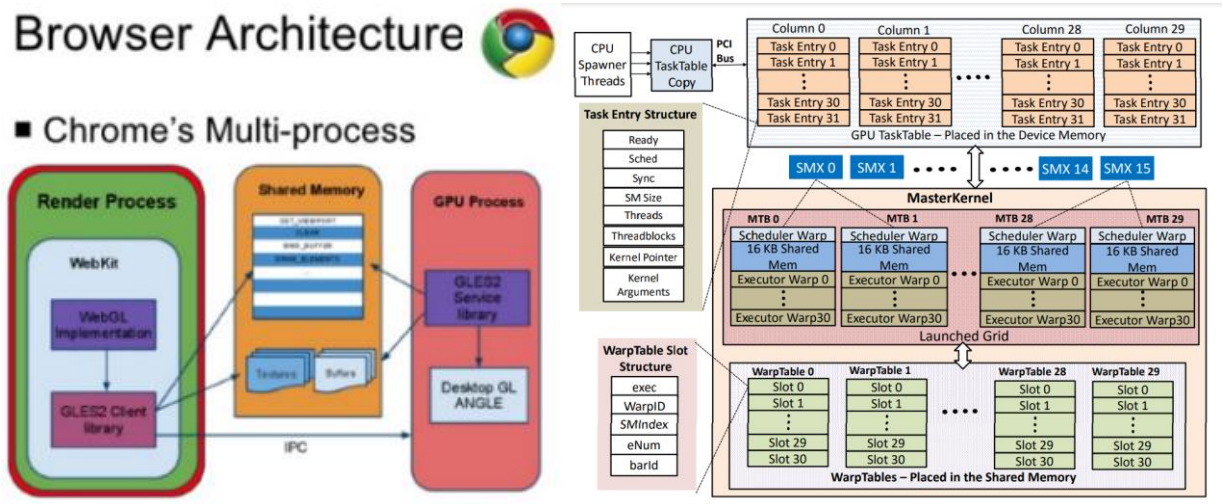



**Figure 13.** Processes running in the google browser and the Master Kernel Composition in the NVIDIA Tesla K40 GPU [43].

Google Chrome uses only one GPU process for each tab. The GPU process can have several sets of rendering commands. The WebGL can transform vertices to pixels and has 3D libraries like THREE.js. [44] aimed for a solution of increasing the performance by using raytracing and octree. Unity WebGL provides methods to place a game available via browser.

## 2.6 Datasets

The CNNs require large amounts of data, which have to be prepared before performing training. Testing and validation datasets are important aspects, because they can increase the accuracy and performance of the model.

To perform classification will be required to label the data for training purposes, in order to determine if a certain X-ray or CT scan of the thorax has Covid or not of if a MRI scan of the brain has tumor, will be required examples of these medical images for cases with and without the disease.

During recent times, many open-source public datasets of Covid-19 have been placed online [45].

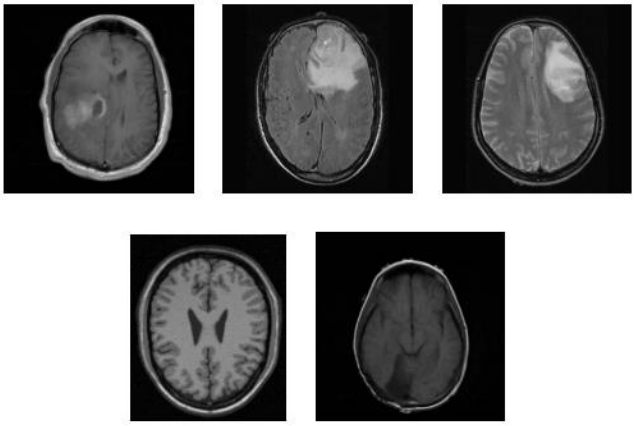


**Figure 14.** Datasets with brain tumor [14].

| No. | Dataset name | Data type | *Size*† | Link |
|---|---|---|---|---|
| 1 | COVID-19 | Text, values(Prevalence) | – | https://github.com/CSSEGISandData/COVID-19 |
| 2 | n-CoV 2019 | Text, numbers (Prevalence) | – | https://github.com/beoutbreakprepared/nCoV2019~~ |
| 3 | COVID-19 image data collection | chest X-ray or CT images | 345 | https://github.com/ieee8023/covid-chestxray-dataset |
| 4 | COVID-CT-Dataset: A CT Scan Dataset about COVID-19 | CT images | 398 | https://github.com/UCSD-AI4H/COVID-CT |
| 5 | COVID-19-CT-Seg-Benchmark | CT images of Lungs | 525 | https://gitee.com/junma11/COVID-19-CT-Seg-Benchmark |
| 6 | COVID-19 CT t segmentation datase | CT images | 100 | http://medicalsegmentation.com/covid19/ |
| 7 | Segmentation dataset nr. 2 | CT images | 829 | http://medicalsegmentation.com/covid19/ |
| 8 | COVID-19-TweetIDs | Text (Social media) | 100 million | https://github.com/echen102/COVID-19-TweetIDs |
| 9 | CORONA VIRUS (COVID-19) TWEETS DATASET | Text (Social media) | 30 million | DOI:10.21227/781w-ef42 |
| 10 | China datalab "Global News" | Text (News) | – | https://doi.org/10.7910/DVN/TU0JDP |
| 11 | China datalab "Climate" | Values (Climatic data) | – | https://doi.org/10.7910/DVN/XETLSS |
| 12 | Coronacases Initiative | 3D CT images | 10 | https://coronacases.org |
| 13 | WorldPop | Values (Demography) | – | https://www.worldpop.org |
| 14 | HDX | Text, values (Humanitarian) | 18,064 | https://data.humdata.org/dataset |
| 15 | WHO Global Health Workforce Statistics | Values (Health workforce) | – | https://www.who.int/hrh/resources/en/ |
| 16 | Apple Mobility Trends Report | Values (Mobility data) | – | https://www.apple.com/covid19/mobility |
| 17 | Google COVID-19 Community Mobility Reports | Values (Mobility data) | – | https://www.google.com/covid19/mobility |
| 18 | Our World in Data | Values (COVID-19 testing data) | – | https://www.acaps.org/covid19-government-measures-dataset |
| 19 | ACAPS | Text and Values (Management measures) | – | https://www.acaps.org/covid19-government-measures-dataset |
| 20 | The Armed Conflict Location & Event Data Project (ACLED) | Values (Security incidents) | – | https://www.acleddata.com |
| 21 | The International Monetary Fund (IMF) | Values (Ecominic outlook) | – | https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19 |
| 22 | BFA Global | Values (Ecominic outlook) | – | https://ourworldindata.org/covid-testing |
| 23 | C3.ai COVID-19 Data Lake | Various | – | https://c3.ai/products/c3-ai-covid-19-data-lake/ |
| 24 | COVID-19 Imaging-based AI Research Collection | Data, literature | – | https://github.com/HzFu/COVID19_imaging_AI_paper_list |

**Figure 15.** List of open source datasets for Covid-19 [45].

Darwin-Labs has a huge online dataset of Covid-19 chest X-rays which is larger than many datasets used for Covid-19 related neural networks [46].

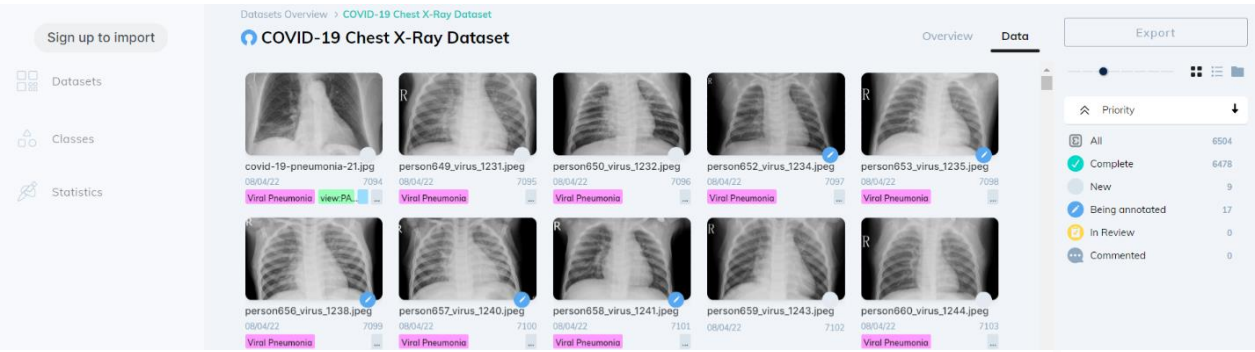



**Figure 16.** Dataset of X-rays for Covid-19 from Darwin-labs, adapted from [46].

Medical images like CT scans or X-rays of the thorax can be used for automated processes of detecting the SARS-CoV-2 virus, which can be as accurate or better than the one done by a human, consuming less time and at cheaper costs when compared with the processes done by laboratories [9]. Many public datasets of Covid-19 can be found in Github and Kaggle.

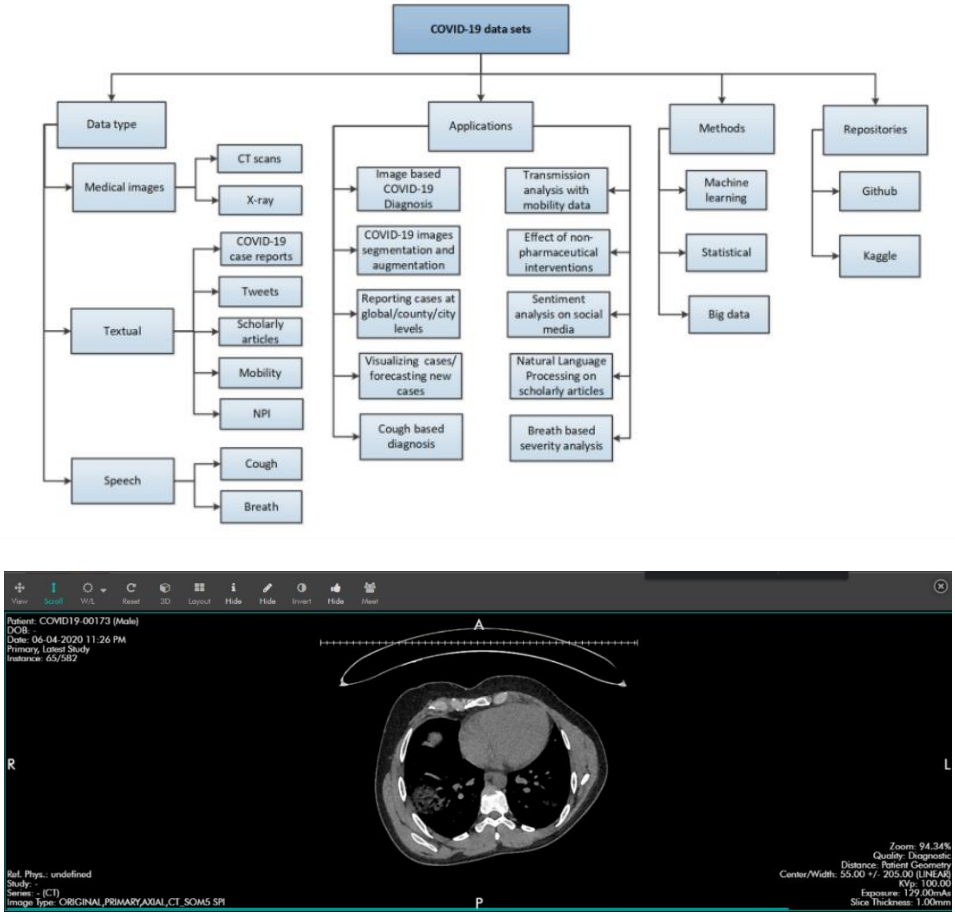



**Figure 17.** Schema of the different types of datasets, like images, text and sounds with possible applications and dataset of Covid-19 CT scans from British Society of Thoracic Imaging [9].

Concerning the process of obtaining datasets for brain tumor detection of magnetic resonance imaging (MRI) scans that have no ionizing radiation, was used as sources the Kaggle and Github websites as well as the cancer imaging archive (TCIA) [47].

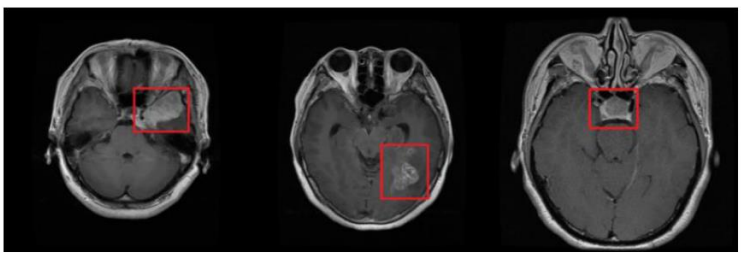


**Figure 18.** Datasets with brain tumor [48].

## 2.7 Convolutional Neural Networks for Disease Detection

The CNNs can be used in image recognition processes, these networks are designed to process pixel data and have layers, being the input of a layer, the output of one of the previous layers. The output can be a label or a segment after using deep learning to perform generative and descriptive tasks [49]. A CNN has several neurons that have biases and learnable weights,which get inputs and makes a weighted sum of these values and passes the result throw an activation function that provides an output. The networks can be used for classification of medical images presenting a prediction of the existence of a specific disease. The CNN models can be compared in terms of accuracy and loss and compared with known architectures like the VGG-16, the ResNet50 or the InceptionV3.

Accuracy:

$$Accuracy = \frac{\text{No of correct predictions}}{\text{Total no of predictions}} \tag{1}$$

Cross Entropy:

$$\text{Cross-entropy} = -\sum_{i=1}^{n}\sum_{j=1}^{m} y_{i,j}\log(p_{i,j}) \tag{2}$$

A confusion matrix can measure the performance of an algorithm commonly used in supervised learning for classification. Concerning the detection of Covid-19 in X-rays, there are four components obtained: the true positives (TP) corresponding to the number of patients correctly classified with Covid-19, that really have the disease, the false positives (FP) corresponding to theincorrectly classified, patients that do not have Covid, the true negatives (TN) patients that were correctly classified and are healthy and the False Negatives (FN) representing patients classified has healthy but do have the disease.

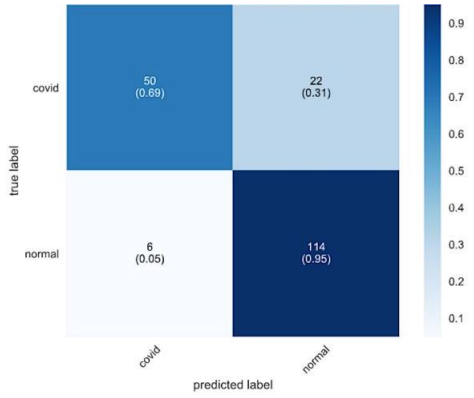



**Figure 19.** Confusion Matrix for Covid-19 Detection using CNN [50].

A Receiver Operating Characteristic (ROC) curve is a graph showing the performance of a

classification model at all classification thresholds. This curve plots two parameters: True PositiveRate and False Positive Rate.

False Positive Rate:

$$FPR = \frac{FP}{N} = \frac{FP}{FP + TN} \tag{3}$$

True Positive Rate:

$$TPR = \frac{TP}{P} = \frac{TP}{FN + TP} \tag{4}$$

Precision:

$$precision = PRE = \frac{TP}{TP + FP} \tag{5}$$

The F1 score measures the equilibrium between the precision and the recall.

Recall:

$$Recall = \frac{TP}{TP + FN} \tag{6}$$

F1 Score:

$$F1Score = \frac{2*precision*recall}{precision+recall} \tag{7}$$

The models can be compared in terms of performance and the results can be calculated.

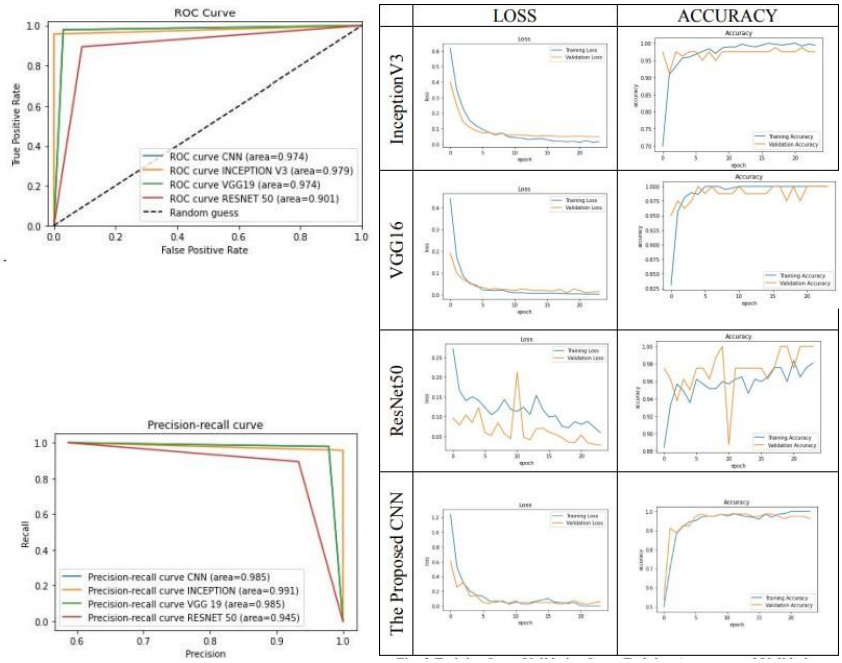



**Figure 20.** Comparison of loss and accuracy between different CNN models and the ROC and Precision-Recall Curves [51].

CNNs have neurons with biases and learnable weights, that receive inputs which are summed

before applying the activation function which generates an output, the network has a loss function. Some diseases can be detected in medical images like X-rays, MRI and CT scans using this methodology, that performs an analysis over several segments and obtains an output result. Convolution has the objective of receiving an input signal from previous seen images and the reference signal of the image will be convolved with the obtained signal producing an output that is passed to the next layer. In this process, small patches of the pixels called filters are taken and compared looking for a match. First the image features are aligned, after, for each pixel the value of the feature image is multiplied by the value of the existing image, these values are added leading to a sum, as a last step the sum is divided by the number of pixels in the feature. This convolution is applied to all the features, not making important where the object is placed in an image.

After the convolution a Rectified Linear Unit (ReLu) activation function is applied. An example of a function can be:

$$f(x) = \begin{cases} 0 \text{ if } x < 0 \\ x \text{ if } x >= 0 \end{cases} \tag{8}$$

Where the negative values are removed and converted to zero. After the activation layer, a pooling layer is applied where the image stack is reduced to a smaller size and obtaining the correspondent values. The next step is to stack up all the layers to get a fully connected network and the predictions are made by comparing the outputs. The last layer of a CNN is the Softmax that is a function that normalizes neural networks output to a value between 0 and 1.

Softmax:

$$\sigma(\mathbf{z})_i = \frac{e^{\beta z_i}}{\sum_{j=1}^{K} e^{\beta z_j}} \tag{9}$$

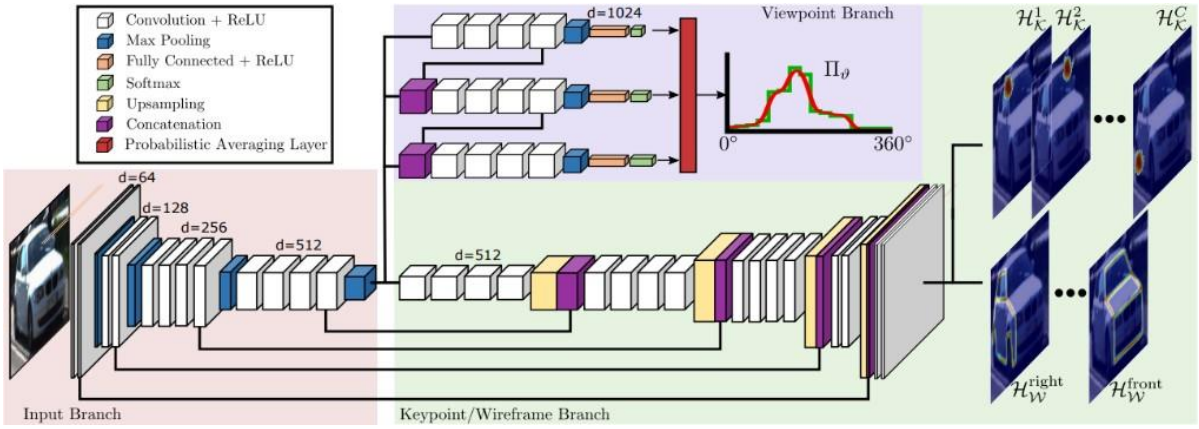



**Figure 21.** Example of a multitask CNN architecture. Retrieved from [52].

Visual Geometry Group is a convolutional neural network that has several layers deep, commonly used for object recognition. Can use the convolution. the ReLu, the pooling and softmax to identify if a medical image has a certain disease when using the correspondent datasets.

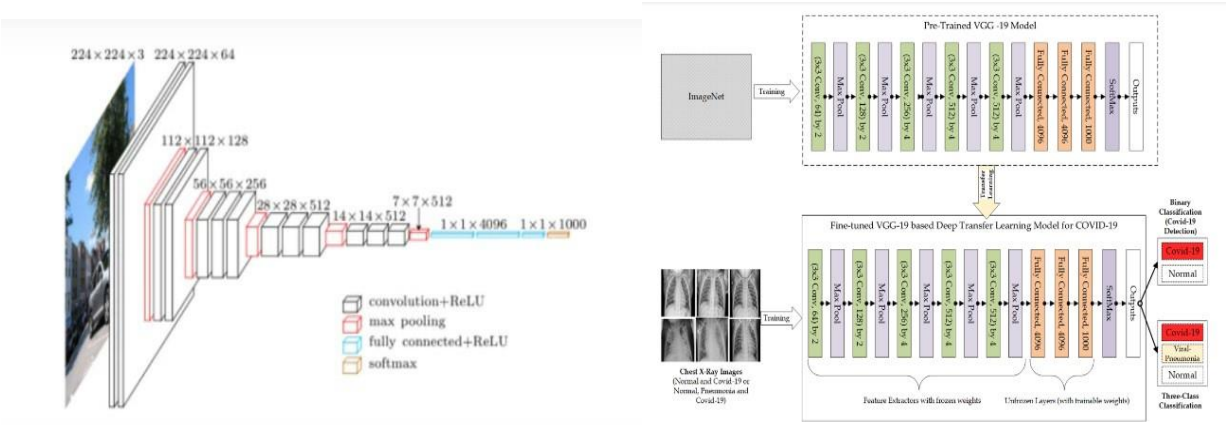



**Figure 22.** VGG-19 architecture and workflow of Deep Transfer Learning Model for Covid-19 [53].

You only look once (YOLO) is a clever convolutional neural network for object detection, the algorithm applies a single neural network to the whole image and after divides into secrions and predicts the probability for each region, being fast and using bounding boxes.

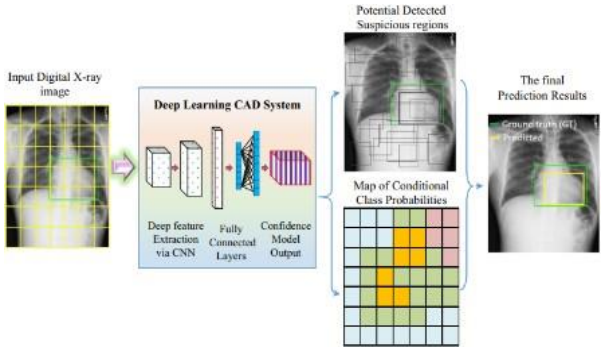



**Figure 23.** Yolo v3 architecture and example of use of Yolo detector for COVID-19. [54].

Residual Network (ResNet) is an artificial neural network (ANN) that can have hundreds of layers, from which some can be skipped and uses the concept of Residual Blocks.

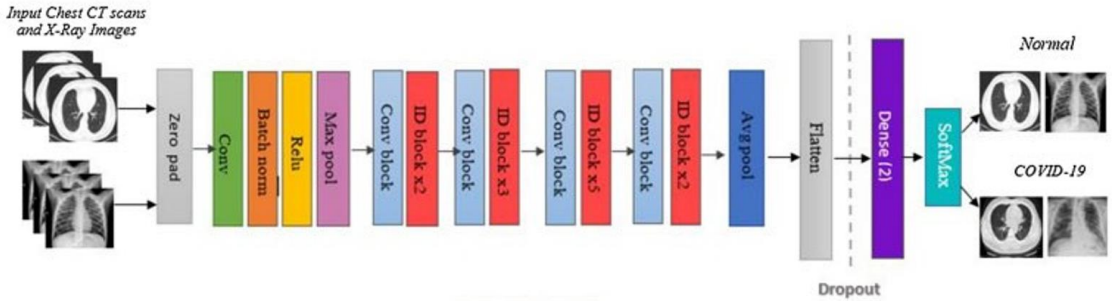
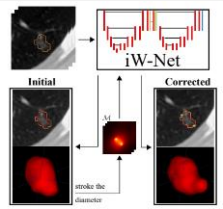
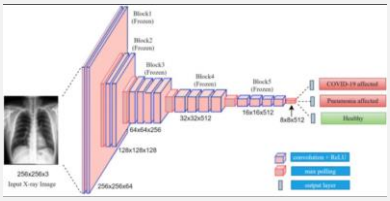
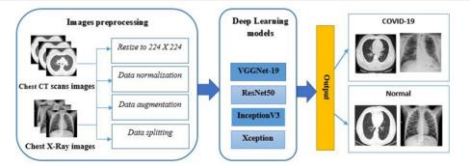
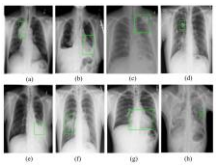



**Figure 24.** Example of ResNet50 model to detect Covid-19 [55].

The selected studies and related work used in this proposal were chosen due to different reasons, some were used due to have the models this dissertation wishes to compare the accuracy results with, some use the RGB channels and others mention sources of datasets and previous research about disease detection.

**Table 1.** Selected studies for detection of Covid-19 on X-rays using CNNs.

<table>
<tr><th>Selected Studies</th><th>Used Materials in this paper</th><th>Objective of the paper</th><th>Processes</th></tr>
<tr><td>Aresta et al., 2019 [56]</td><td>The Yolo detector and the use of boundary boxes for predictions.</td><td>Detect lung cancer using CNNs and analysis of medical images of the thorax</td><td>Segmentation of images<br>  </td></tr>
<tr><td>Sekeroglu and Ozsahin, 2020 [51]</td><td>ResNet-50 and VGG-16 Models</td><td>Detection of Covid-19</td><td>Covid-19 detection via CNN<br>  </td></tr>
<tr><td>Hamad et al., 2022 [57]</td><td>VGG-19 model.</td><td>Medical Images Diagnosis</td><td>VGG-19 for Covid-19 classification<br>  </td></tr>
<tr><td>Zhang, 2020. [46]</td><td>The Darwin dataset, images classification and methodologies to prepare the datasets.</td><td>Segmentation of lung images. Detect Covid-19 using medical images.</td><td>Type of images<br>
<table>
<tr><th>Status</th><th>Number of Images</th></tr>
<tr><td>Total</td><td>6504</td></tr>
<tr><td>COVID</td><td>521</td></tr>
<tr><td>Non-COVID</td><td>5983</td></tr>
<tr><td>Semantic Lung Mask Provided</td><td>6396</td></tr>
<tr><td>Semantic Lung Mask Provided & COVID</td><td>439</td></tr>
<tr><td>Semantic Lung Mask Provided & Non-COVID</td><td>5957</td></tr>
<tr><td>Semantic Lung Mask Missing</td><td>108</td></tr>
</table></td></tr>
<tr><td>Chouat and others., 2022 [55].</td><td>Use of the RGB channels</td><td>Classifier to detect COVID-19</td><td>Comparison between deep learning models for Covid-19 detection<br>  </td></tr>
<tr><td>Al-Antari ad others 2020 [54]</td><td>Perform CNN in X-rays, the use of Yolo and bounding boxes over X-rays of the thorax.</td><td>Covid-19 Detection and adaption to detect other diseases like pneumonia.</td><td>Use of bounding boxes for detection<br>  </td></tr>
</table>

The image produced by the X-ray equipment is based on a basic principle of the relationship between the rays that are emitted and the rays that are received, after passing through a certain material. A beam of X-radiation energy is produced through a generator, which will focus on the region

of the body to be visualized. Part of that energy is absorbed by the body, depending on the density of the structures and the rest falls on a film or detector, forming the radiograph.

## 2.8 Treatment of the Photoplethysmographic Signal

The Photoplethysmography (PPG) is an optical technique to detect changes of the blood volume, giving important information about the cardiovascular system; The waveform 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 [58].

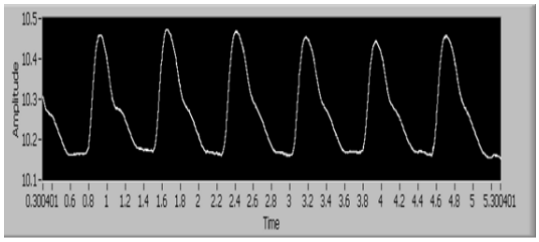



**Figure 25.** The PPG signal acquired in LabView [59].

By using the 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).

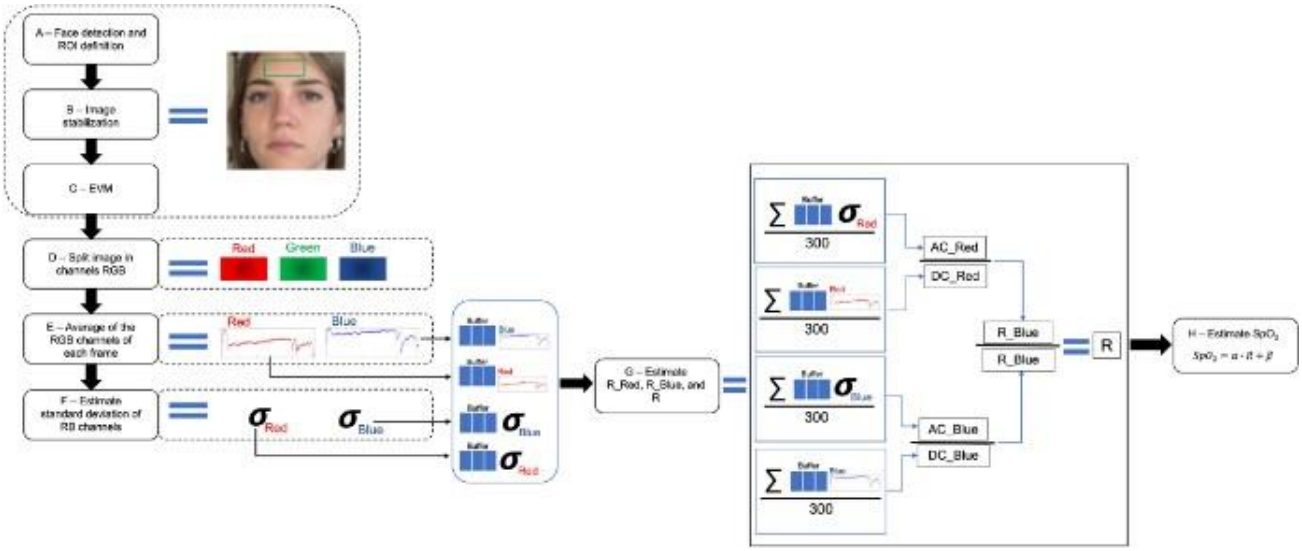



**Figure 26.** Framework to retrieve an estimation of SpO2 and Framework for respiration detection from the PPG signal [60].

The formula used to calculate the SpO2 can be based in the AC and DC of the blue and green channel [61].

$$\mathrm{SpO}_2 = A - B\frac{\mathrm{AC}_{\mathrm{RED}}/\mathrm{DC}_{\mathrm{RED}}}{\mathrm{AC}_{\mathrm{BLUE}}/\mathrm{DC}_{\mathrm{BLUE}}} \tag{10}$$

To determine the cardiac frequency, previous studies have showed that the green channel has stronger plethysmograph signal [62].

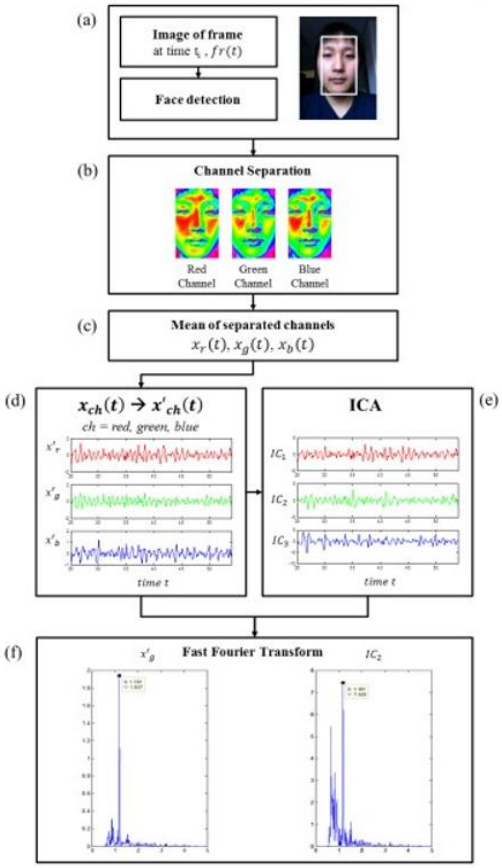



**Figure 27.** Heart rate extraction [62].

Any channel, red, green and blue can be normalized via a function where μ is the average and σ the standard deviation of Xch(t) respectively.

$$x'_{ch}(t) = \frac{x_{ch}(t) - \mu_{ch}}{\sigma_{ch}} \tag{11}$$

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

# Chapter 3 – Applications for the Patients

3

This chapter describes the artefacts which in this case is a set of applications and processes to achieve the objectives proposed and answer the research questions. There are two type of applications, one to be used by patients and another to be used by doctors.

The section in cause mentions how the research was performed in order to find an interface for the patient that makes the process of obtaining the vital signs easier and more accurate. Chapter 4 will mention the processes used to make the readings of vital signs from a camera sensor more effective, the use of a CNN to classify if an uploaded X-ray, CT scan or MRI scan has a certain disease, how a web spectrogram was implemented to show the sound signal captured by a stethoscope and a final application that records all the data for the patients.

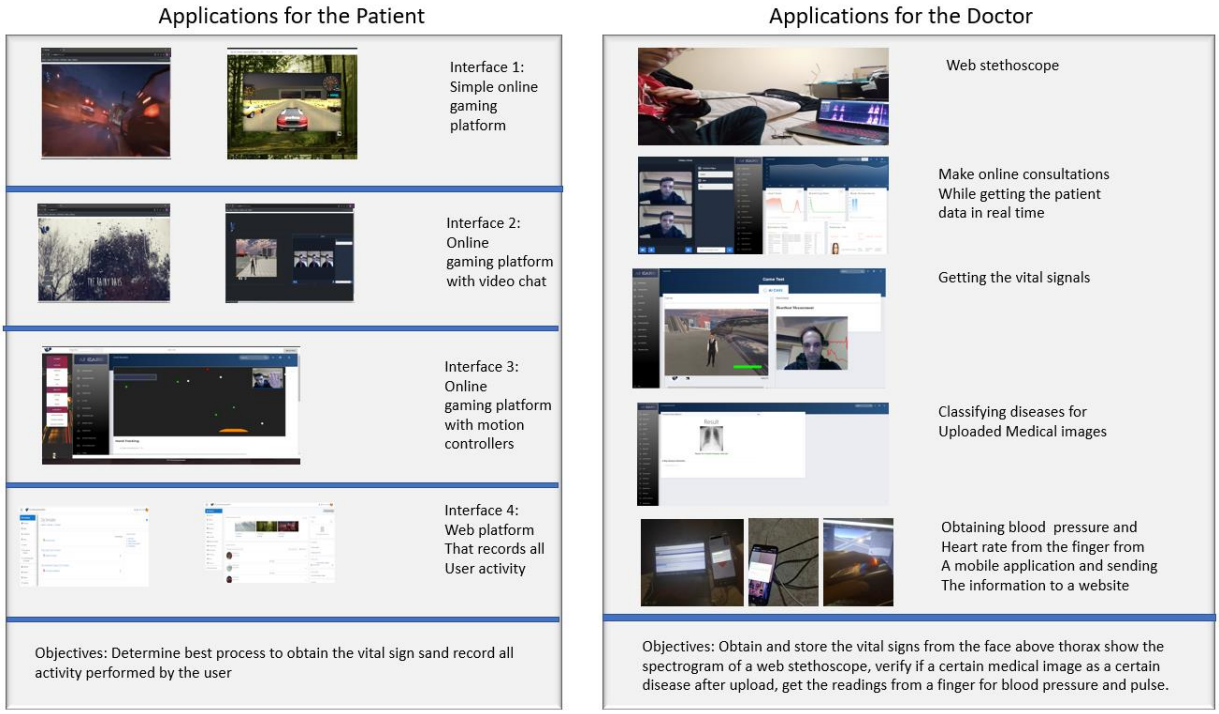



**Figure 28.** Schematization of the applications used and objectives.

## 3.1 Applications for the Patients to Obtain the Vital Signs

The section shows the work performed to compare different interactions of the users with different serious online gaming interfaces in order to understand which is more effective for obtaining the readings of vital signs.

The analysis used four different systems, one of them was mainly developed in Hypertext Preprocessor (PHP) that allows to integrate the other three and view all the interaction of the users with the several systems providing logs that are treated to create a usability dataset. In order to understand which type of interface mechanisms and processes allow to provide a more accurate measurement of the vital signs, three online gaming platforms were developed, a simple

one in C# .Net Core with a SQL Server database, a second one in NodeJS where an online video chat was added using the webRTC library and the database used was MongoDB, a third one mainly developed in PHP with motion controllers where users can play without using the keyboard or mouse interacting with the system via gestures with the hands, or moving the eyes or moving the full body with a MySQL database. The forth was made in PHP using the open source code of Moodle and the provided MySQL database, that allows to have the 3 previous ones in one system and also records and register all the activity done by the patients, providing logs to generate an usability dataset that can be trained for ML regression and make predictions.

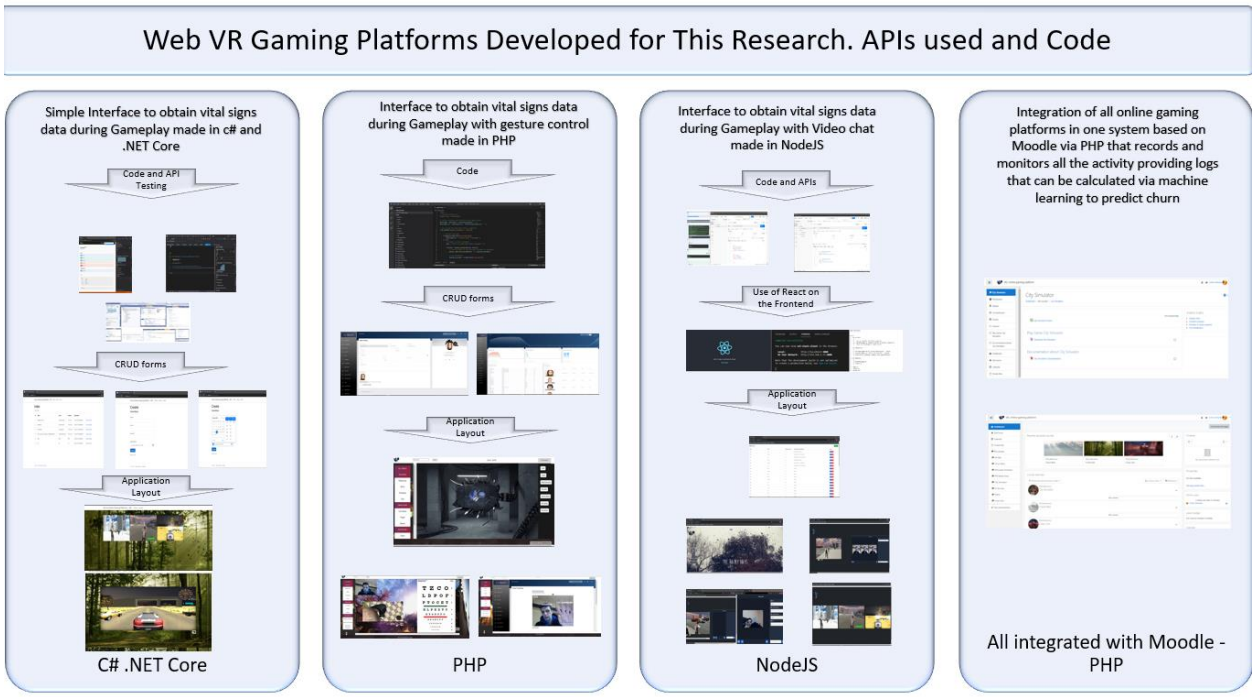



**Figure 29.** Description of the different interfaces of full stack applications developed to understand which process is more efficient to obtain the vital signs.

The schematic of the proposed solution is based on the implementation of 4 virtual web online gaming platforms, to check which provides a better process of interaction between doctor and patient and more accurate readings. Interface nmjets.

During gameplay via web cam, it is possible to get readings of the vital signals of the users, while playing usually the patients are sited or on a rest and calm state allowing to make the measurements of vital signs data more accurate for the defined patterns, if the user was running or is not at rest the parameters to be used like the minimum level and the maximum level have to be others, so in order to achieve a necessary rest state, a strategy of making the readings during gameplay was followed.

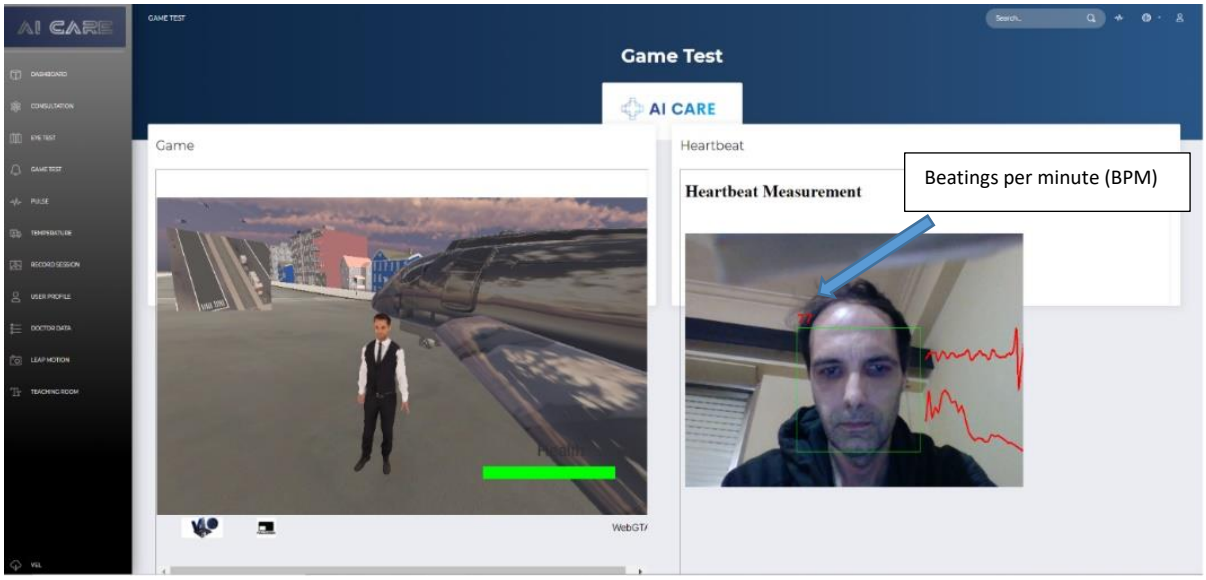



**Figure 30.** Obtaining the vital signs while playing a serious game in this case the cardiac frequency given in beats per minute (BPM) on real time and showing the respective plot adapted from the code of [63].

## 3.2 Game Development

For the proposed solution in order to place the users in a rest state because it is very important when getting the vital signs for making the readings analysis more accurate (if the patients have been doing exercise or other activities and situations like certain diseases or certain medications, the parameters to be used for the vital signs readings will have to be others). The online games objective to facilitate the process of interaction between doctor and patient, like the execution of physio therapeutical exercises with motion controllers or running simulators to read the vital signs.

**Figure 31**. Some of the developed simulators and games in Unity with C# for training purposes.

For some of the games developed the integrated development environment (IDE) used was the Unity Game Engine with C#, via this technology the AI was implemented via scripting interacting with the animations and implementing mechanism of proximity and collision in order to respond to the actions of the user

**Figure 32**. Development of some of the serious games with Unity 3D.

The applications used to obtain the vital signals with motion controllers were mainly made in JavaScript using specific libraires that let the infra-red camera to work as a sensor and by using AI algorithms for computer vision allow to detect the region of interest (ROI) which in the solution proposed were the hands, iris of the eyes and the bones structure allowing the patient to interact with the system by moving the eyes, the hands or the full body.

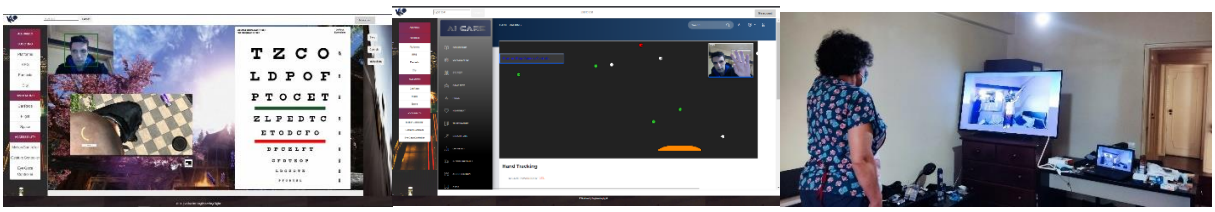



**Figure 33.** Applications and games developed for healthcare activities.

## 3.3 Development of Online Platforms for Obtaining Vital Signs

With the objective to understand which interaction process is more efficient between patient and doctor, four different interfaces were developed in order to verify which one provides more effective reading results. The first interface was made in .Net core and C# and is simple, where the user plays online serious games and via webcam the vital signs are obtained after AI treatment of the recorded information. The second interface was developed using Hypertext Preprocessor (PHP) and has motion controllers for the hands and eye movements, allowing to make the training accessible to people of different ages and different disabilities. The third interface was made with NodeJS mainly and MongoDB a non-relational database (NoSQL), where the user has the aid of a video chat interacting with the doctor, which may help in terms of making the process of obtaining vital signs faster. The fourth corresponds to an integration of the previous 3 developed mainly in PHP and using the Moodle open source code to get all the logs and activities done by the users during their interaction with the system provided via online gaming.

## 3.4 Application Programming Interface System

Several APIs techniques were used in this project, concerning the .NET Core process, this one was developed via Visual Studio 2019 which allows to diagnose the speed and performance. The Entity Framework Core was used as object-database mapper. These APIs were built via the .NET Framework 5.0  and interacts with the SQL Server. The MVC architecture was followed, and the entities were created and the DBContext used as well as the controllers for these entities following the standards of the RESTful API architecture pattern. In the picture below we can see the association with the database using a connection string.

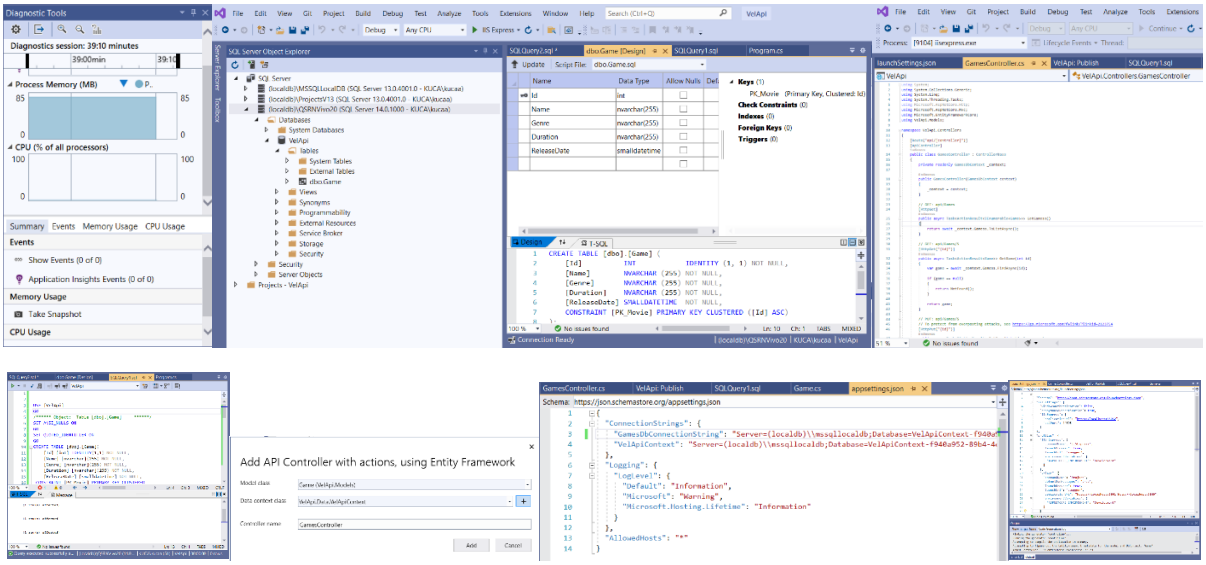



**Figure 34**. The .Net Core API development.

Two mechanisms were used to test the .Net core API, one was based on Swagger, and the other one via postman, which allow to see the objects passing and test the RESTful web services in cause.

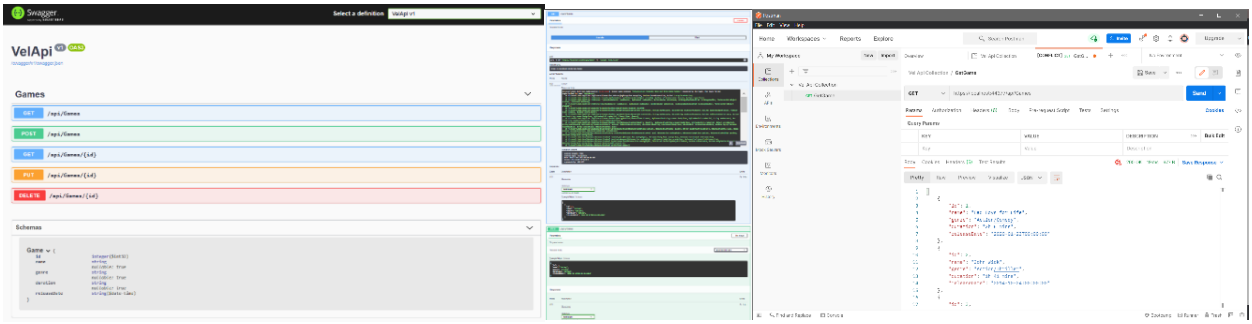



**Figure 35.** API testing.

## 3.5 Login System

To create an account it is asked the username and the password two times in order to increase security. On the initial stage, the login was developed in PHP using an API that will check the introduced values by the user with the information in the database. On the pictures below we are able to visualize 2 forms one for login and another for creating an account.

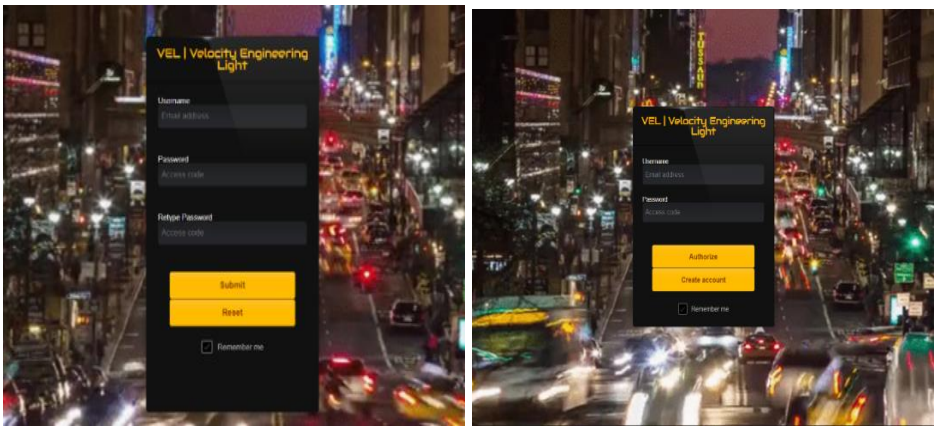



**Figure 36**. Login System (Initial version).

The API receives the HTTP requests that are processed, analyzed and compared. The passwords are encrypted via an algorithm and stored in the database; currently is using the Linux Kerberos authentication protocol, which means that the passwords do not circulate on the network but tickets that are issued for each credential. In the final stage of the project, the login was based on the one provided by the Moodle module. In order to enter the application it is necessary to click on the login link on the top right of the page. At the moment is allowing anonymous login for test purposes, and also has a button for account creation.

On the final version in order to enter the application, it is necessary to fill a form that asks for username, password, email, first name, surname, city and country. When this information is correctly introduced, it will send an email to the given email account with a link that will activate the account in the online system.

The usernames and passwords are stored in the MySQL database. The passwords appear encrypted after being processed throw an algorithm of encryption, and the server uses a certificate authority (CA). In order to achieve security some changes were done on the code in order to assure a higher level of protection when accessing the application. Currently the administrator can configure and delete user accounts. In the initial prototype, the passwords where stored in a table of the database with an encrypted code as shown on the picture below:

· Opções

| | id | username | password | created_at |
|---|---|---|---|---|
| Edita Copiar Apagar | 1 | | | 2019-08-18 04:30:22 |
| Edita Copiar Apagar | 2 | test | $2y$10$k3/z7eVm3U5bq6rf6VWr5.FiDl2ZFYk0x1CVdAEKv7a... | 2019-08-18 04:33:32 |
| Edita Copiar Apagar | 3 | test2 | $2y$10$4//yUYJUgNxFzAheYrBHnONbc8pW99kt6C/t/kNi/9U... | 2019-08-18 16:59:14 |
| Edita Copiar Apagar | 4 | 123 | $2y$10$6gwxg7o01FS/gpmdlg7LbepoWbb/GlCEfZmEe4ZaXvp... | 2019-08-18 18:43:45 |
| Edita Copiar Apagar | 5 | test9 | $2y$10$/mGjRvbSdQpoUonji3fzi.TjUoOCF46S/Ri.ohUIMFN... | 2019-08-18 19:36:35 |
| Edita Copiar Apagar | 6 | test14 | $2y$10$cysvE5nuiAJ0Jb6UlJSdCOTonvlE/er9UXhCqV08PBf... | 2019-08-18 20:48:01 |
| Edita Copiar Apagar | 7 | test19 | $2y$10$VP52QaKnmF7lgSQKElx82.35SJiAJgMES74XRNoxe2l... | 2019-08-18 20:51:03 |
| Edita Copiar Apagar | 8 | scmoro | $2y$10$HsHbUcmBTj322D8KQwqx9eHodBophBWSld/Tsl3UTu2... | 2019-08-20 11:33:32 |
| Edita Copiar Apagar | 9 | test99 | $2y$10$xwaBQ0VyjEhlH0oQ1ujXz.8oljzbumb.JpojRSu/A6o... | 2019-09-01 01:40:32 |

**Figure 37.** Users table.

With the Kerberos protocol, the passwords do not circulate on the network using a ticketing system in order to provide security to the application.

## 3.6 Applications Servers

On this project was used 2 different applications servers for different virtual machines, namely Internet Information Services (IIS) and Apache Tomcat. In order to provide access to the development environment some scripts were used and the router configured.

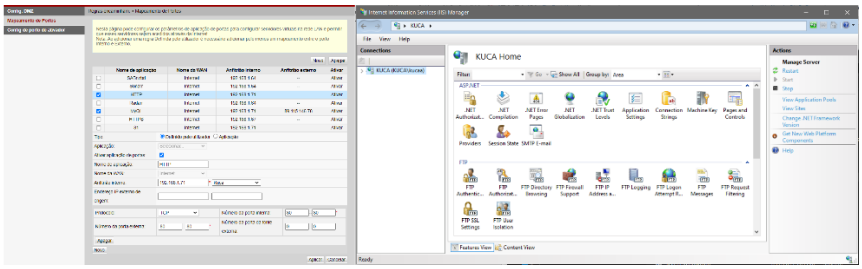



**Figure 38.** Apache Tomcat and IIS configuration.

## 3.7 Backend

For one of the applications was used NodeJS from OpenJS which is a runtime environment that provides the possibility of using JavaScript on the backend.

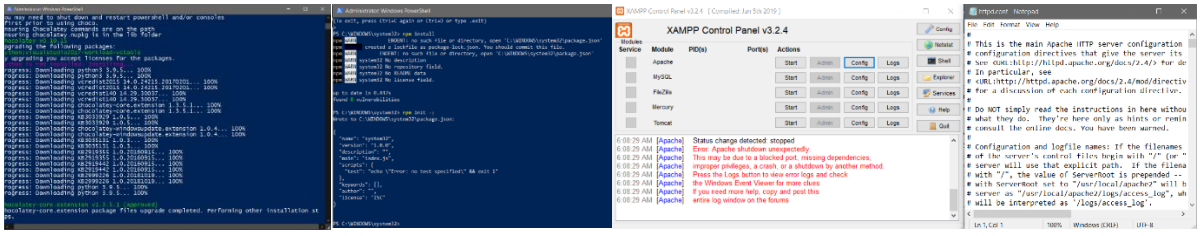



**Figure 39**. Configuring NodeJS.

On this part of the project was used mongoose, express.js, express-handlebar, body-parser, nodemon and EJS. The file GameController.js has most of the operations defined. The API was tested with postman as showed on the picture below.

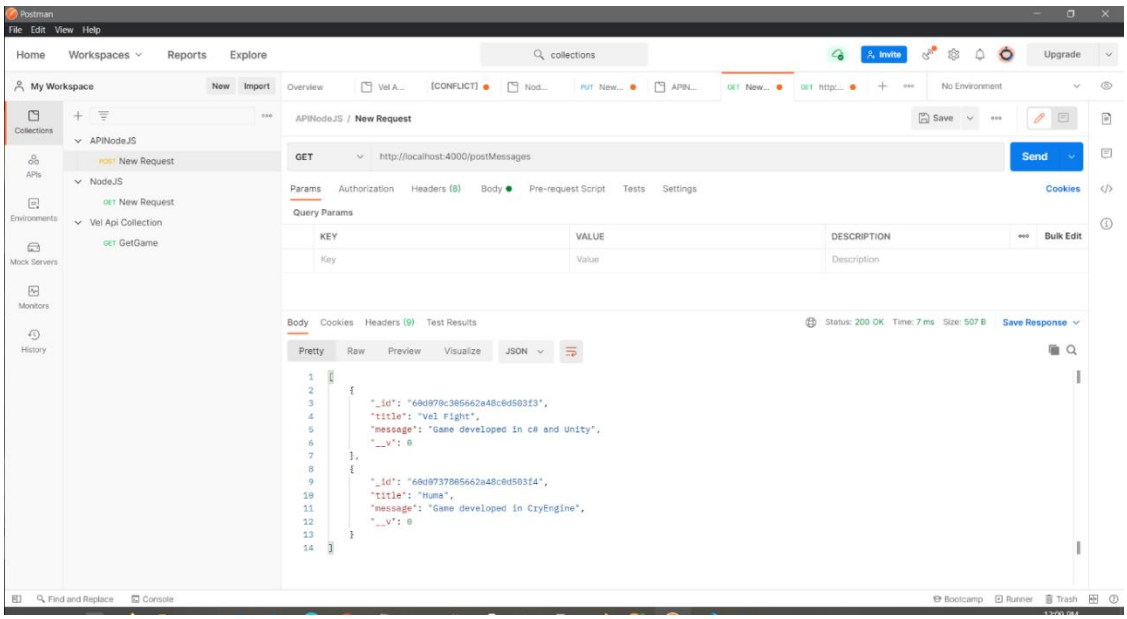



**Figure 40.** Testing the API for an application with NodeJS and MongoDB.

For the application developed with C# the APIs were also tested using Swagger.

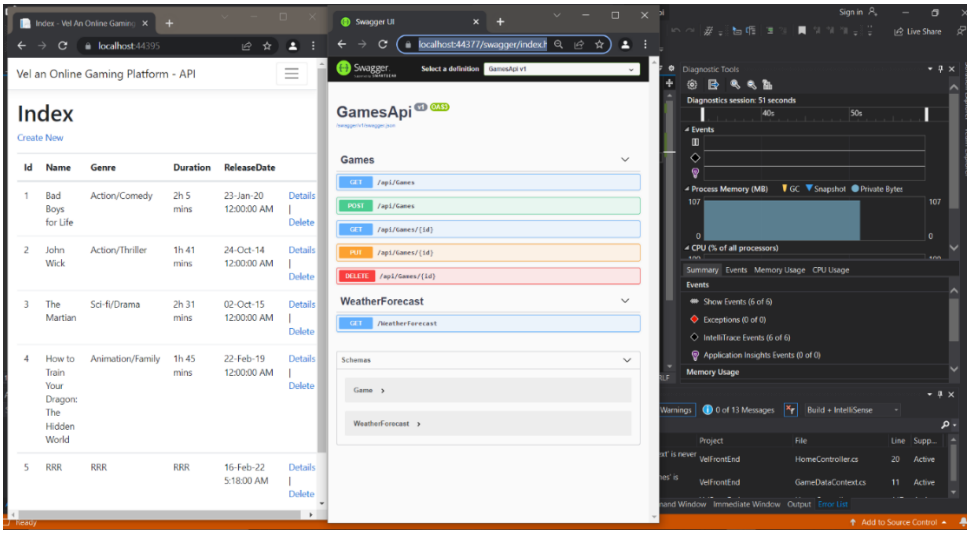



**Figure 41.** Testing the API with Swagger for an application with .Net core and SQL server.

By taking a closer look to the class GamesController, we can see the use of the entity framework and the use of libraries like Linq and MVC that allow to perform the CRUD operations to a SQL server database, the picture below also shows the code to perform a get and a put of the entity game.

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Threading.Tasks;
using Microsoft.AspNetCore.Http;
using Microsoft.AspNetCore.Mvc;
using Microsoft.EntityFrameworkCore;
using GamesApi.Models;

namespace GamesApi.Controllers
{
    [Route("api/[controller]")]
    [ApiController]
    public class GamesController : ControllerBase
    {
        private readonly GamesDbContext _context;

        public GamesController(GamesDbContext context)
        {
            _context = context;
        }

        // GET: api/Games
        [HttpGet]
        public async Task<ActionResult<IEnumerable<Game>>> GetGames()
        {
            return await _context.Games.ToListAsync();
        }

        // GET: api/Games/5
        [HttpGet("{id}")]
        public async Task<ActionResult<Game>> GetGame(int id)
        {
            var game = await _context.Games.FindAsync(id);

            if (game == null)
            {
                return NotFound();
            }

            return game;
        }

        // PUT: api/Games/5

        [HttpPut("{id}")]
        public async Task<IActionResult> PutGame(int id, Game game)
        {
            if (id != game.Id)
```

**Figure 42.** Controller class to perform the CRUD operations written in C#.

A SSH key was created and putty was used to connect to the web server with Linux and the files were uploaded via FileZilla.

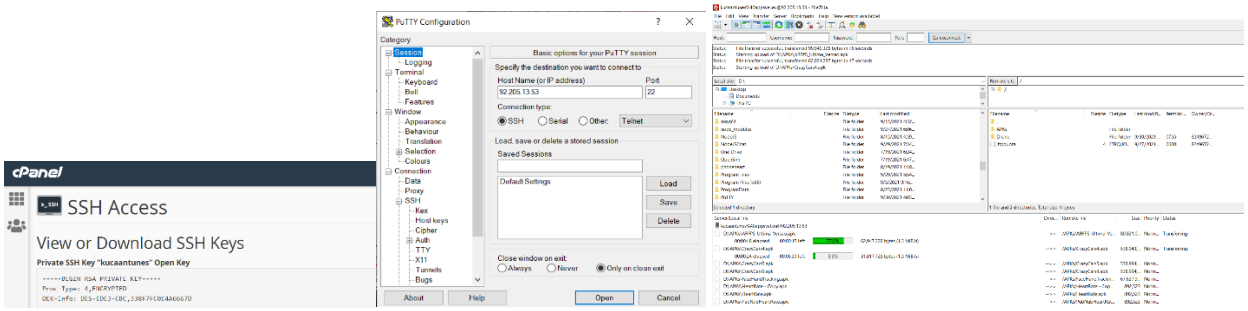



**Figure 43.** Use of SSH Key, Putty and FileZilla.

## 3.8 Platform Dashboard

After clicking on the link provided by the registration email, the user can enter the system and play the several games provided on the platform.

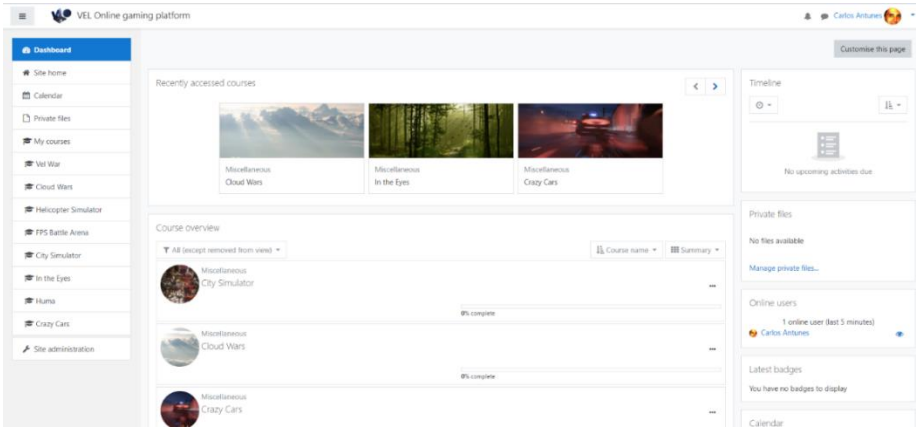



**Figure 44.** Dashboard for managing the interfaces of the patients.

The user has the option to configure his dashboard. On the default, display shows the recent games played. On the bottom of the dashboard appears all the games and the option to enroll. On the top right corner appears the chat and an option to configure the user profile. The left menu bar shows the available games, a link to the dashboard, another to the site home page, one for the calendar and another to access the private files.

By accessing one of the games, it is provided information about the game and a link to play or download the game. All games have a forum and a manual with information about the games. The information about the participants of the game is also displayed.

## 3.9 Database Development

For this project, one of the databases was developed with MySQL that connects with the application backend code. The current database of Moodle was also used and added tables and stored procedures in order to be possible to add game functionalities to the open source web solution. A Backup database was created on another web server and also stored the SQL code that allows to create the all features of the database via PHPMyAdmin. Some functionalities were inserted via designer and some SQL scripts had to be executed in order to provide the final solution. The passwords are stored in a database table and encrypted that require to run a method to decrypt.

The SQL server database was mainly developed via SQL scripting where stored procedures, functions, triggers and views were added.

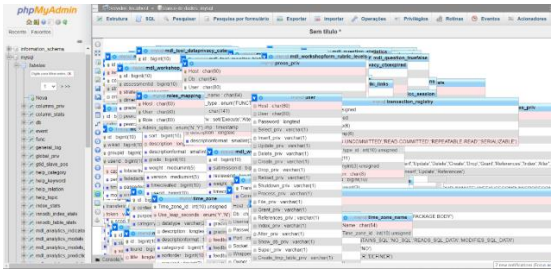


**Figure 45.** MySQL database of one the applications of the patient.

Concerning the .Net application it was used the SQL server database, the CRUD operations are done via API.

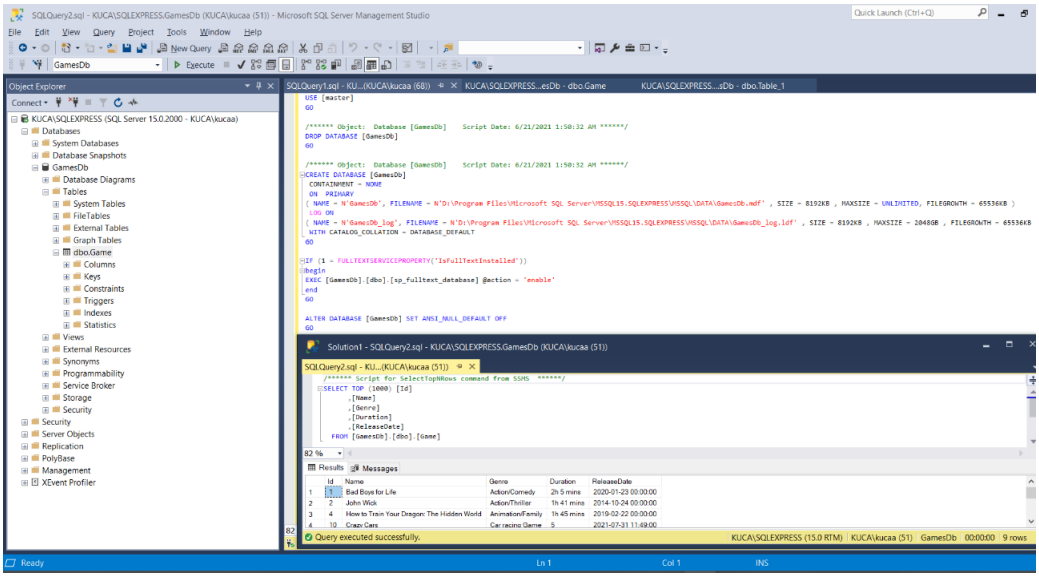
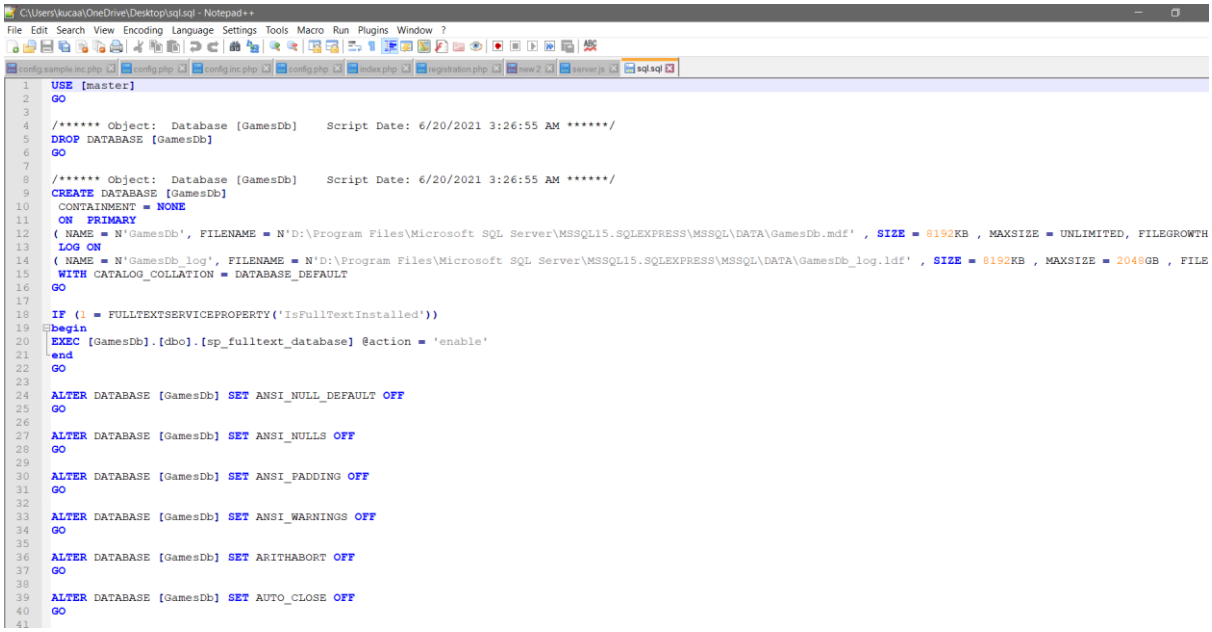


**Figure 46.** Configuring the SQL server database.



```
USE [master]
GO

/****** Object:  Database [GamesDb]    Script Date: 6/20/2021 3:26:55 AM ******/
DROP DATABASE [GamesDb]
GO

/****** Object:  Database [GamesDb]    Script Date: 6/20/2021 3:26:55 AM ******/
CREATE DATABASE [GamesDb]
 CONTAINMENT = NONE
 ON  PRIMARY
( NAME = N'GamesDb', FILENAME = N'D:\Program Files\Microsoft SQL Server\MSSQL15.SQLEXPRESS\MSSQL\DATA\GamesDb.mdf' , SIZE = 8192KB , MAXSIZE = UNLIMITED, FILEGROWTH
 LOG ON
( NAME = N'GamesDb_log', FILENAME = N'D:\Program Files\Microsoft SQL Server\MSSQL15.SQLEXPRESS\MSSQL\DATA\GamesDb_log.ldf' , SIZE = 8192KB , MAXSIZE = 2048GB , FILE
 WITH CATALOG_COLLATION = DATABASE_DEFAULT
GO

IF (1 = FULLTEXTSERVICEPROPERTY('IsFullTextInstalled'))
begin
EXEC [GamesDb].[dbo].[sp_fulltext_database] @action = 'enable'
end
GO

ALTER DATABASE [GamesDb] SET ANSI_NULL_DEFAULT OFF
GO

ALTER DATABASE [GamesDb] SET ANSI_NULLS OFF
GO

ALTER DATABASE [GamesDb] SET ANSI_PADDING OFF
GO

ALTER DATABASE [GamesDb] SET ANSI_WARNINGS OFF
GO

ALTER DATABASE [GamesDb] SET ARITHABORT OFF
GO

ALTER DATABASE [GamesDb] SET AUTO_CLOSE OFF
GO
```

**Figure 47.** Script that allows to create a full database.

Concerning the application developed with NodeJS that has the video chat, the database used was the NoSQL MongoDB.

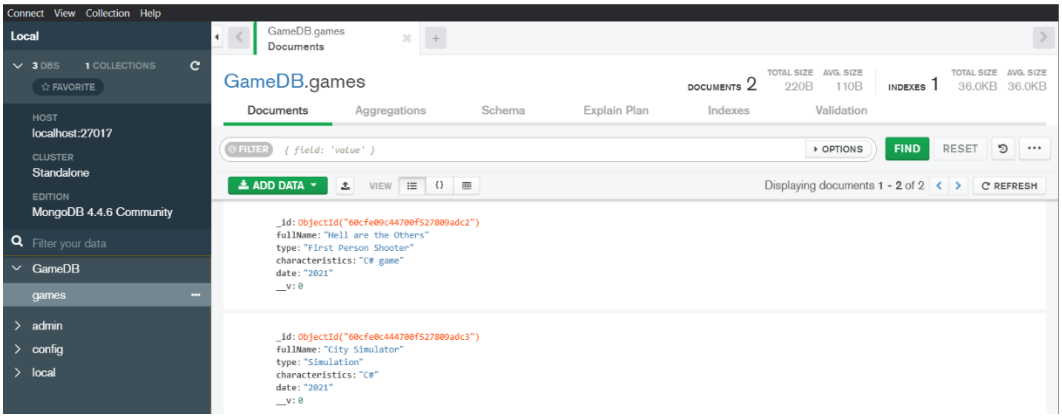



**Figure 48.** MongoDB in a cloud system.

## 3.10 Profile System

With the help of the code provided by Moodle it was possible to create a profile system that allows to associate files and pictures to each user. On the profile, each player can see his stats for each game as well as all the activities and logs he has done while using the application. This system allows to see all the games he has subscribed and also the messages he received, the forum posts and the blog posts. The email, name and profile picture can be changed and has some similarities with the process followed by the Facebook application.

## 3.11 Eye Gaze

Use of Node JS to track the eye movement with the use of WebGazer.js. this technology allows to do visual tests, and the orange spot shows where the patient is looking.

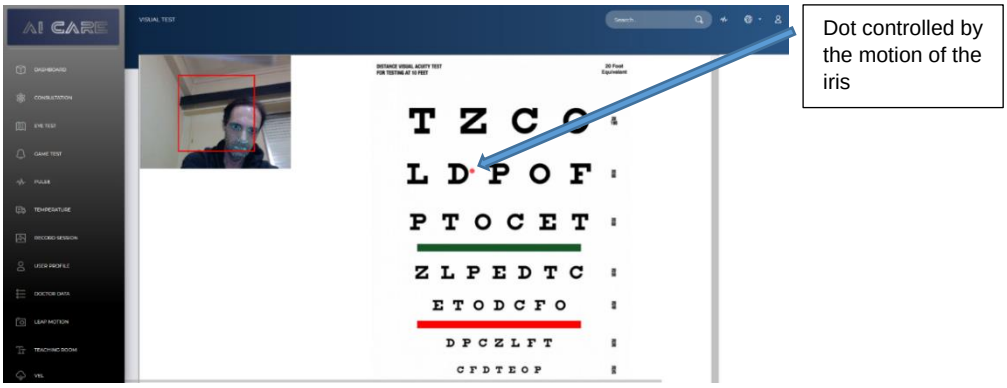



**Figure 49.** Performance of the visual test with eye gaze via JavaScript.

## 3.12 Frontend

On the frontend of the .NET core application an API helper class was created in order to associate the frontend project with the previously created API, using the associated url and port of the API. An Home controller was used on the front end of the application allowing to make the API calls.

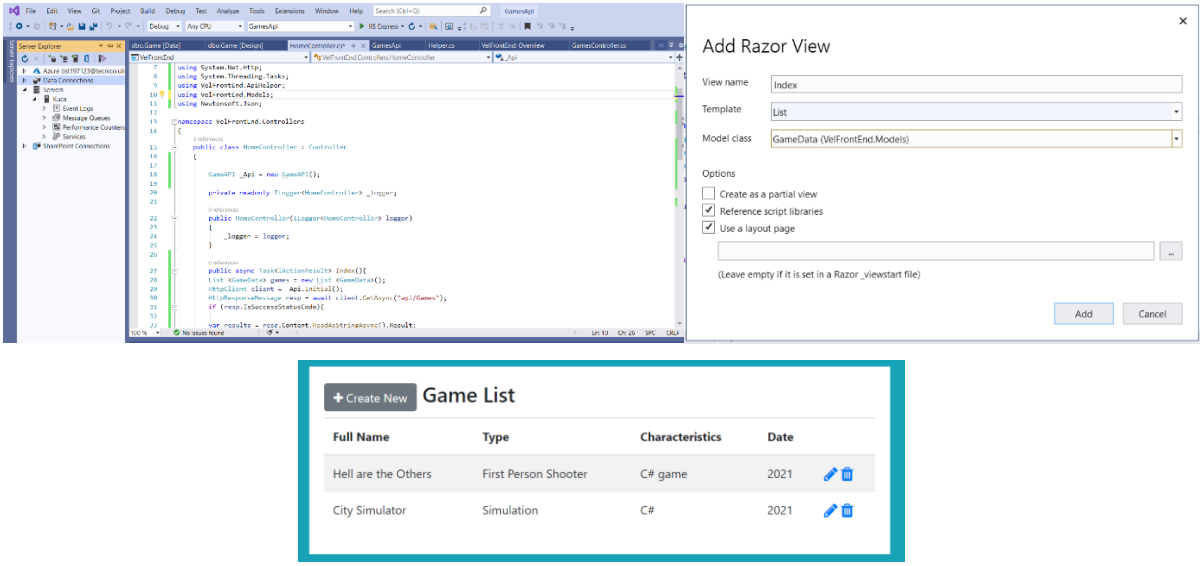



**Figure 50.** Development of frontend and views in .Net Core and NodeJS.

For the application in NodeJS was used react, which allows to create a production environment and also was imported the packages redux, react-redux and reduxt-thunk.

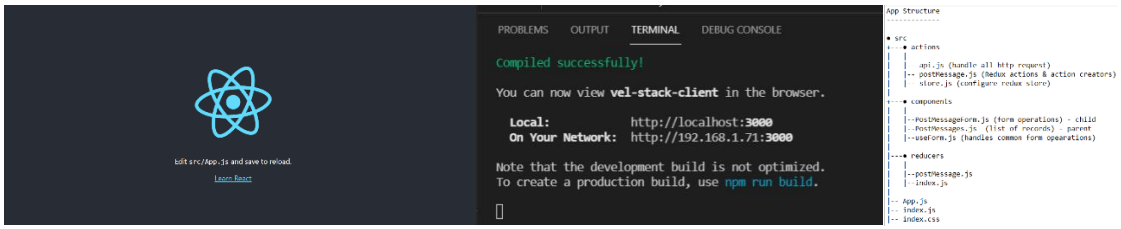



**Figure 51.** Development of frontend with React.

Angular 7 was also used and imported the dependencies angular/material, angular/cdk, angular/animations and angular/flex-layout.

Azure was used for the .Net core application allowing to measure the CPU usage, the network speed and the memory used.

## 3.13 Production Environment

In order to test the best interface to obtain the vital signs via browser, four full stack web applications were developed. The first was made with .NET Core, SQL Server and Angular, the games were implemented via unity.

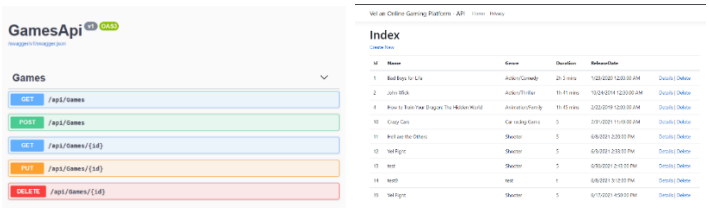



**Figure 52.** Development of full stack with Angular.

The second full stack application was developed with NodeJS, React, Angular and the database used was MongoDB.

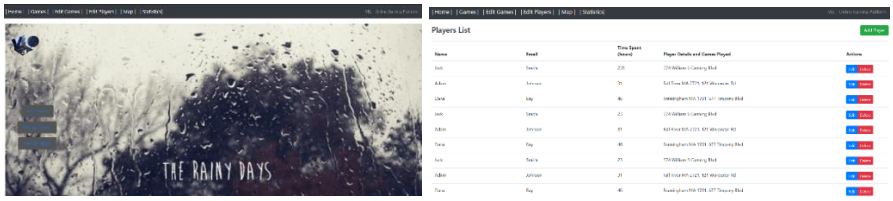



**Figure 53.** Development of full stack with React.

Concerning the third application developed, it was used PHP, MySQL and simple HTML and Javascript, and does not use MVC.

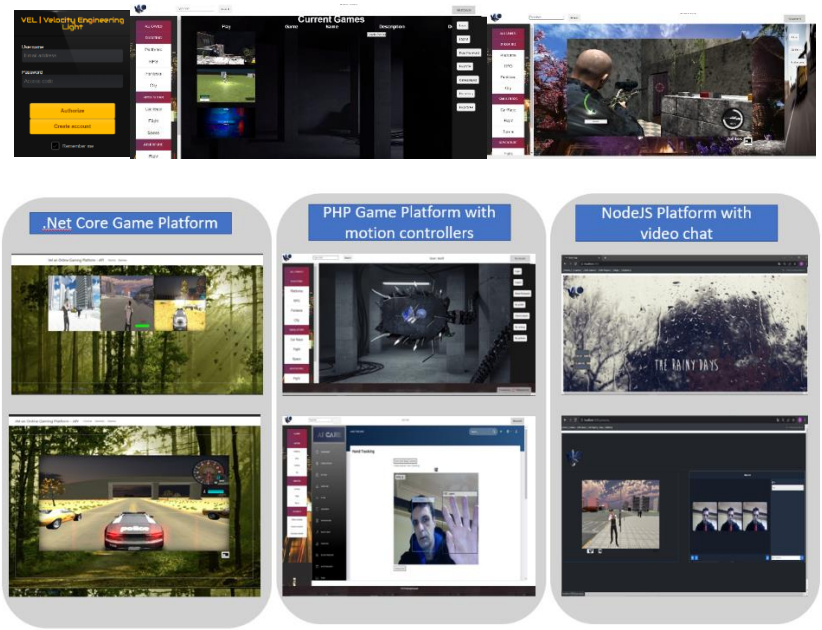



**Figure 54.** Development of full stack applications.

The final application integrate all the previous, plus chat, profile, authentication Oauth, statistics, user administration among other modules, the development strategy followed was based in continuous integration allowing to add all the web development performed during this dissertation in one solution.

# Chapter 4 – Applications for the Doctors

4

This section describes the application for the doctor named AI Care and has two main divisions, the first has a primary care approach where the vital signs are described and how they were obtained via 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: heart, lung and brain.

## 4.1 Contextualization and Overview

Via artificial intelligence (AI) for Computer Vision (CV), the vital signs like body temperature, blood pressure, systolic values, diastolic values, cardiac frequency, oxygen saturation and respiratory rate were obtained and stored, in order to understand the health status of the patient.

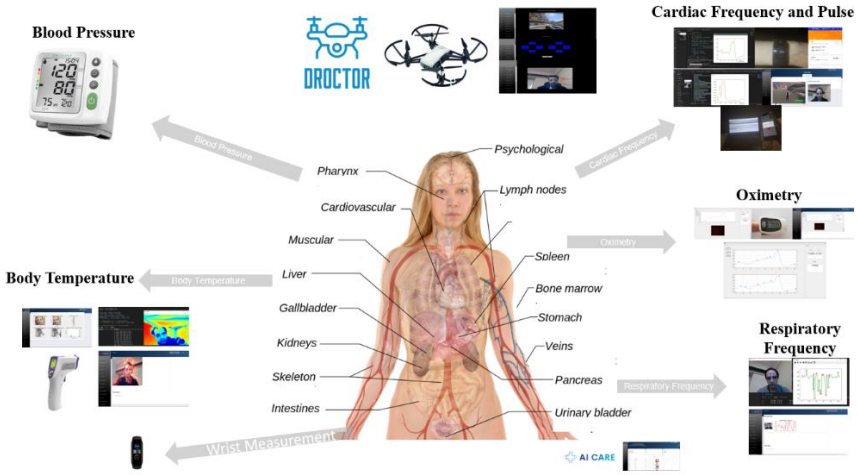



**Figure 55.** Overview of the processes and artefacts to obtain the vital signs.

With the objective to improve the diagnosis on 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. Four applications were developed: An AI Stethoscope, a medical image classificatory, a virtual chat with vital signs data and an integrator that stores the information in a MySQL database and manages the information, so doctors can have a more complete archive of a certain patient.

The dissertation presents an integrated solution developed mainly in 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.

Chapter 4 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. On 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 AI stethoscope was developed showing the spectrogram obtained, helping the doctors on their diagnosis and a classifier using deep learning to treat the X-ray, CT scans and MRI scans after upload aiding in terms of informing if there is a possible disease using the Visual Geometry Group (VGG) 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 is called AI care and an extended application that obtains the vital signs via the camera of the drone is called Droctor.


**Figure 56.** 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 on real time. On a secondary care point of view, this study focuses on 3 organs: heart, brain and lungs; in order to better check the healthy status of these organs, two applications were developed: an AI 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 doctors can have a more

complete archive of a certain patient. The database has 19 tables, some of them connected via foreign keys, where the information inserted by the doctor is stored.

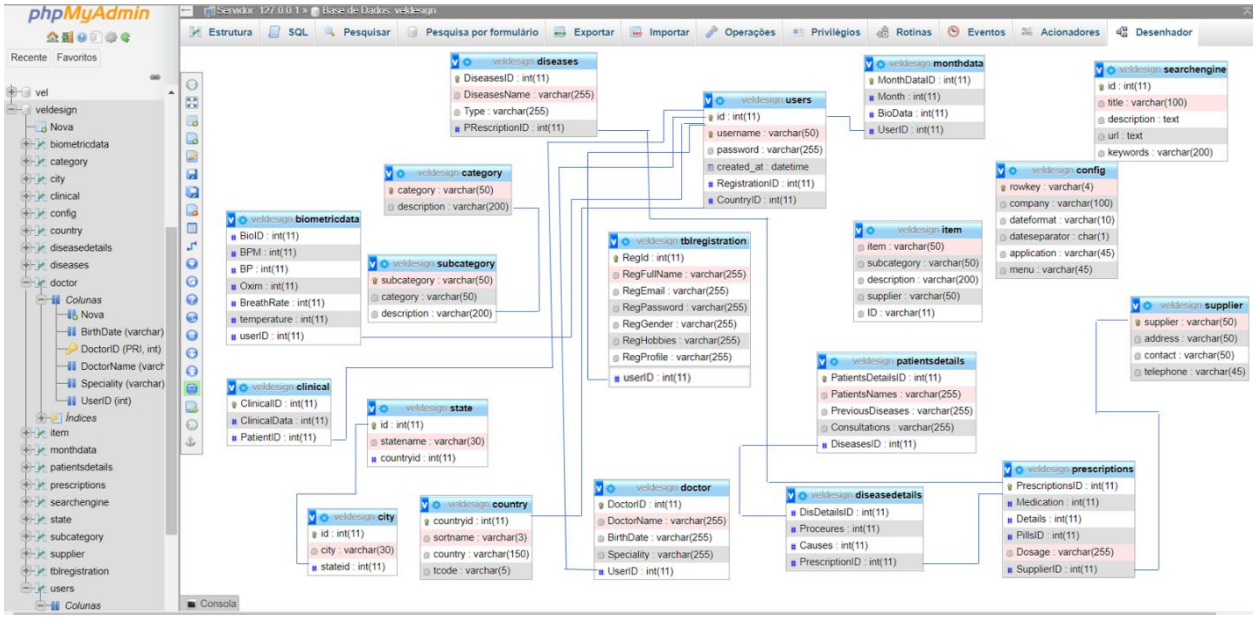



**Figure 57.** Entity relationship model of the AI Care database.

## 4.2 Online Consultations

Concerning the objective of making a medical analysis more effective, the presence of the doctor 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.

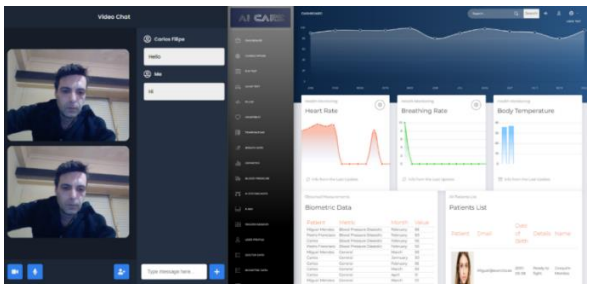



**Figure 58.** During the chat, the doctor can visualize the historical data of the patient. Adapted from the code of [64].

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

**Blood Pressure**:

**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.

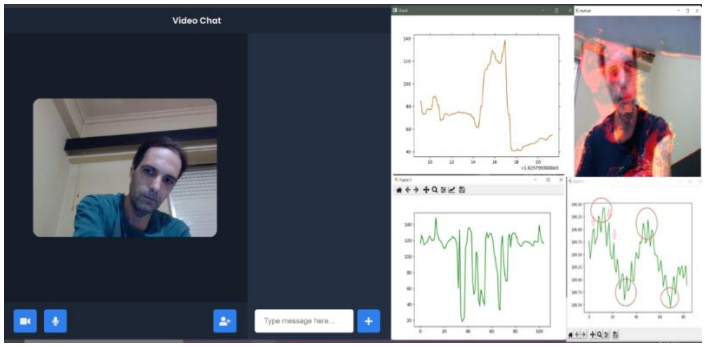



**Figure 59.** Analysis of the breath rate.

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. The heartrate 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 motion and the face detection (RGB) of the patient.

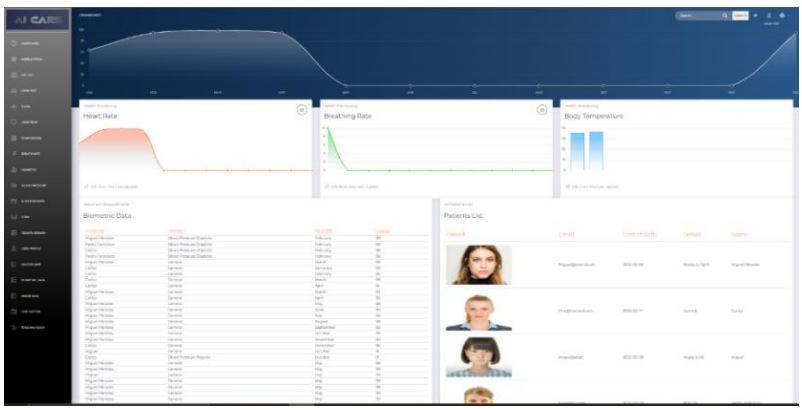



**Figure 60.** The AI care application.

## 4.3 Primary Care Analysis based in obtaining the Vital Signs

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).

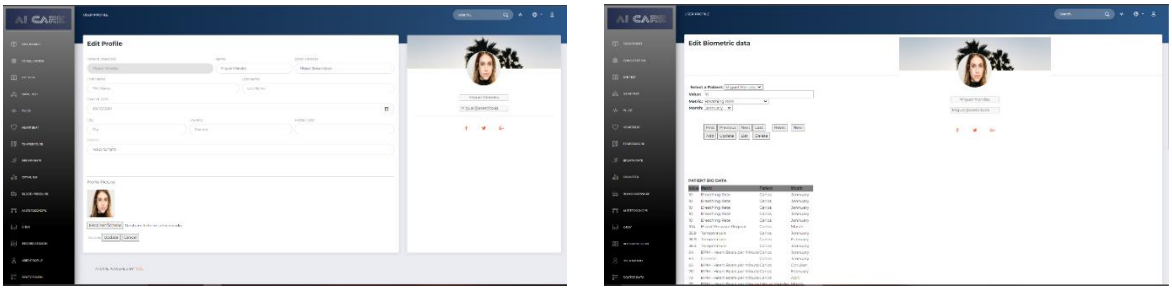



**Figure 61.** Data for a specific patient.

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 doctors to understand the health state of a patient and determine the severity level.

## 4.4 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. Two applications were developed to get the temperature via web camera, one in Python and the other in Matlab.

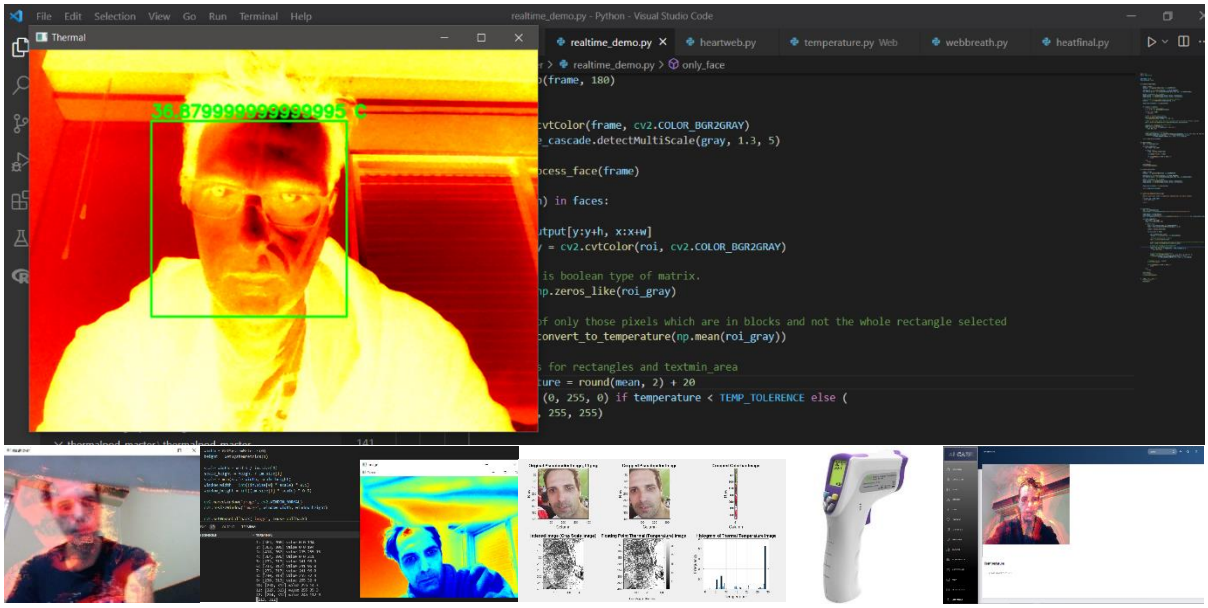



**Figure 62.** Obtaining body temperature via Python and Matlab. Adapted from the code [65].

## 4.5 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. A mobile application was developed in java to obtain this value using the camera of the phone and by detecting the face of the user.

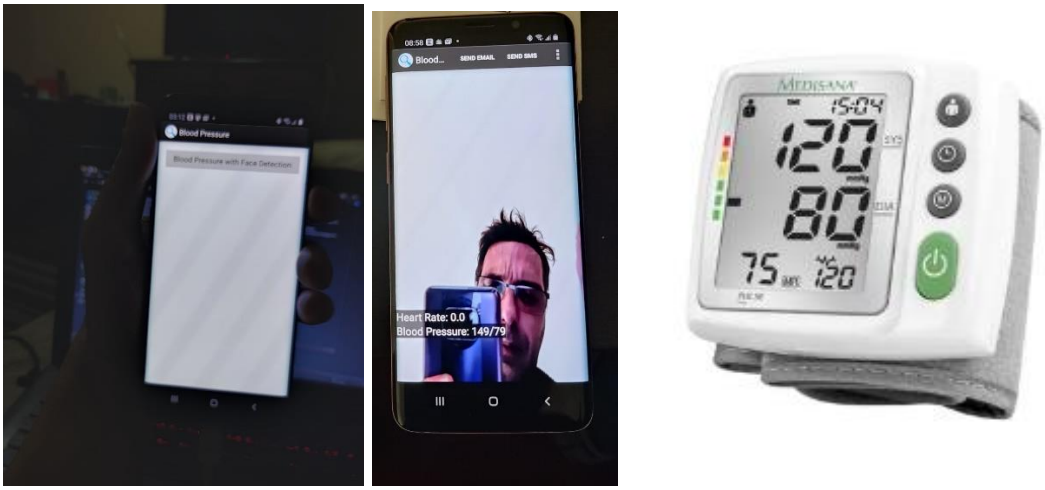
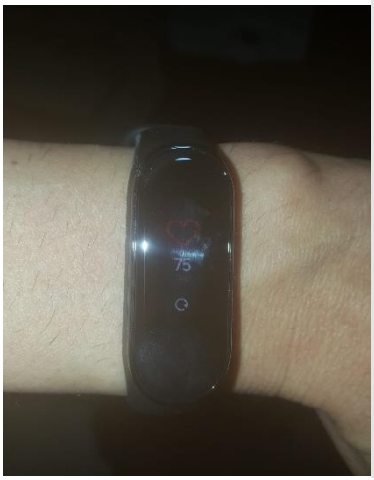



**Figure 63.** Application developed in Java for mobile and a Pulse Blood Pressure Monitor.

## 4.6 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 during gameplay we have developed an application that measures the cardiac frequency in real time with the use of Python that is base 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.



```python
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 64.** 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. During the gameplay the application will track the face of the player first and afterwards will report the heartbeat in real time. The picture below is the heartbeat measurement on a web application with the use of OpenCV.

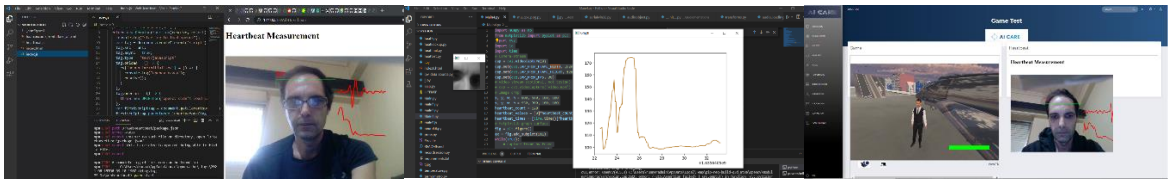



**Figure 65.** Different processes for heartbeat detection and usage of a serious game to get the state of rest to perform the analysis.

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 calculating also 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 doctor.

The application should have an alarm system that triggers a contact to the correspondent 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, that 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 the figure above 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.

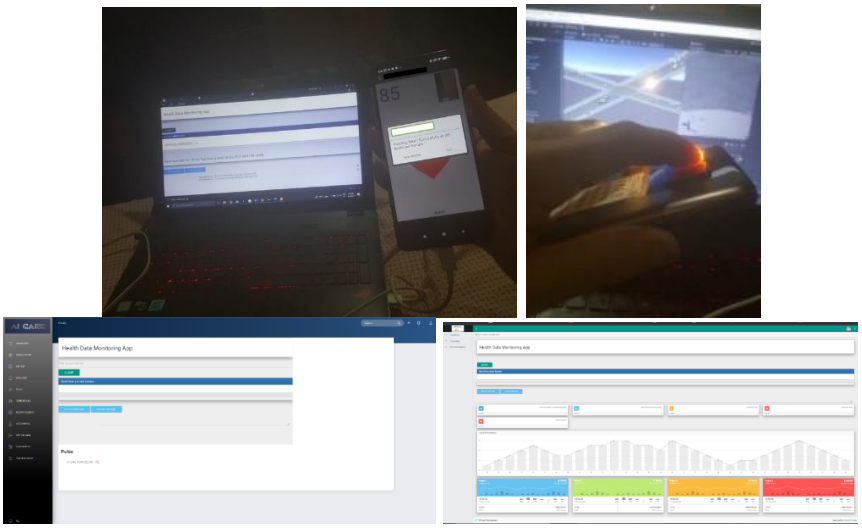


**Figure 66.** Detection of heartbeats via finger (light required for reading) and the web application.

## 4.7 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 (SaO2). SaO2 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 appropriate lightning and placing the thumb close to the web cam.

The formula used to calculate the SpO2 can be based in the AC and DC of the blue and green channel [61].

$$\mathrm{SpO_2} = A - B\frac{\mathrm{AC_{RED}}/\mathrm{DC_{RED}}}{\mathrm{AC_{BLUE}}/\mathrm{DC_{BLUE}}} \tag{10}$$

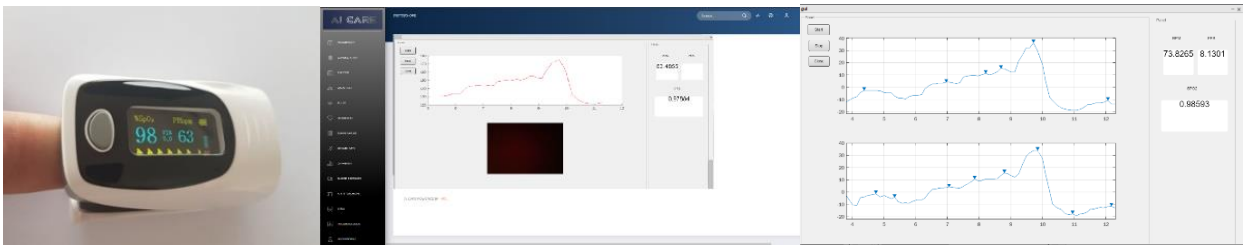


**Figure 67.** Obtaining the percentage of oxygen on the blood arteries.

## 4.8 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 breads 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.

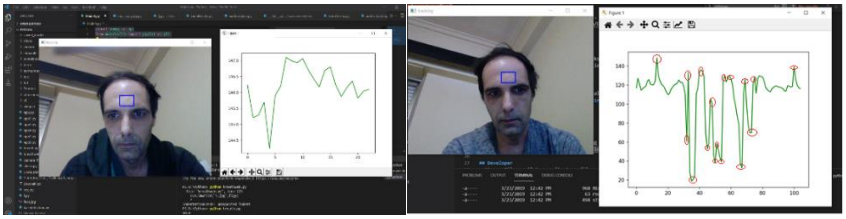


**Figure 68.** Breath rate detection and comparison

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

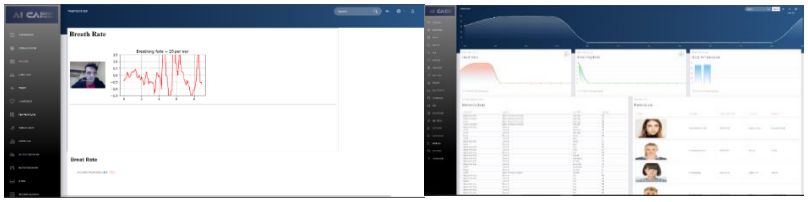


**Figure 69.** Obtaining the breath rate and adding to the clinical record of the patient. Adjusted from the code [66].

## 4.9 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.

### 4.9.1 Analysis of Medical Images via a Convolutional Neural Network

An application was developed with the VGG-16 architecture 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 doctors 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.

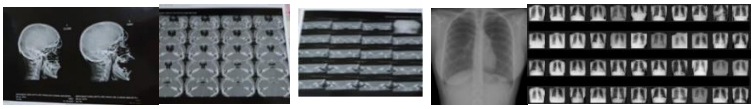


**Figure 70.** Obtaining the datasets for head and chest.

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.

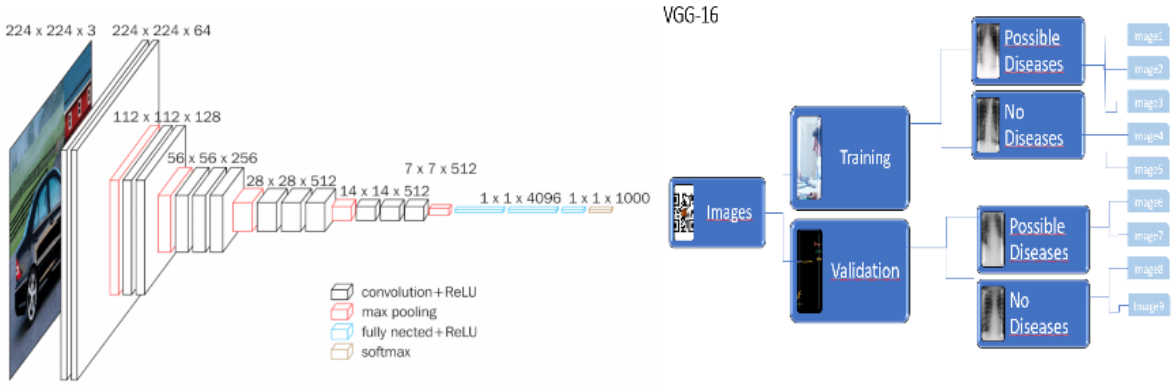



**Figure 71.** The VGG-16 architecture and the process for datasets validation and testing.

A Receiver operating characteristic (ROC) analysis was done to evaluate the performance of the diagnostic tests and the accuracy of the statistical models. The formulas used in the trained Keras models are showed below.

False Positive Rate:

$$FPR = \frac{FP}{N} = \frac{FP}{FP + TN} \tag{12}$$

True Positive Rate:

$$TPR = \frac{TP}{P} = \frac{TP}{FN + TP} \tag{13}$$

Micro-average Precision:

$$PRE_{micro} = \frac{TP_1 + \cdots + TP_k}{TP_1 + \cdots + TP_k + FP_1 + \cdots + FP_k} \tag{14}$$

Macro-average Precision:

$$PRE_{marco} = \frac{PRE_1 + \cdots + PRE_k}{k} \tag{15}$$

The confusion matrix allows to measure the performance of an algorithm in supervised learning and the Receiver Operating Characteristic (ROC) curve shows the level of performance

for a classification model taking usually in account the True Positive Rate (TPR) and the False Positive Rate (FPR).

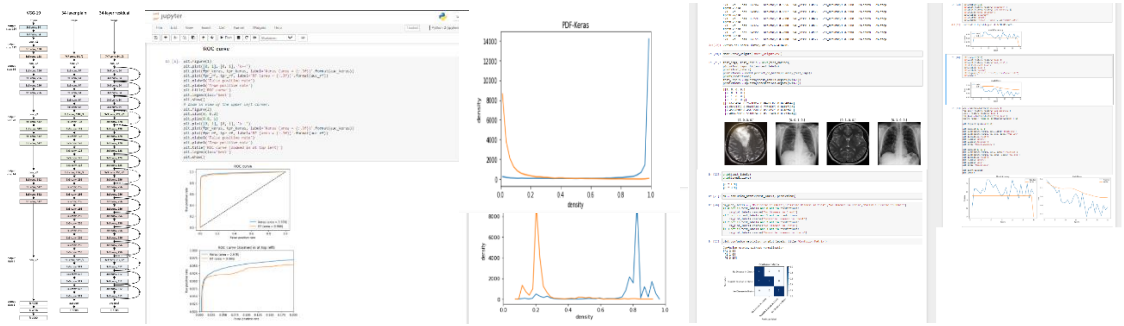


**Figure 72.** Analysis of the VGG-19 and the Resnet34 architectures for classification. Python Jupyter code to generate the ROC Curve; the Probability Density Function (PDF) and the Confusion Matrix of the classification process used.

A general web application made mainly with JavaScript and PHP 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.

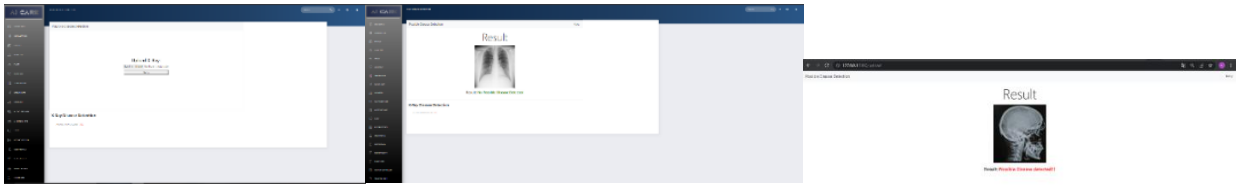



**Figure 73.** Usage of AI Care by uploading an image and showing the results (possible disease or no disease detected). Code adapted from [67].

## 4.9.2 Showing the spectrogram of a Stethoscope

To help the doctors in analyzing the organs of the lungs and the hearts, a web application was developed mainly with Angular and TypeScript 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 (XJR) 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 frequencies between the 20 Hz to 20 kHz usually depending on the age.

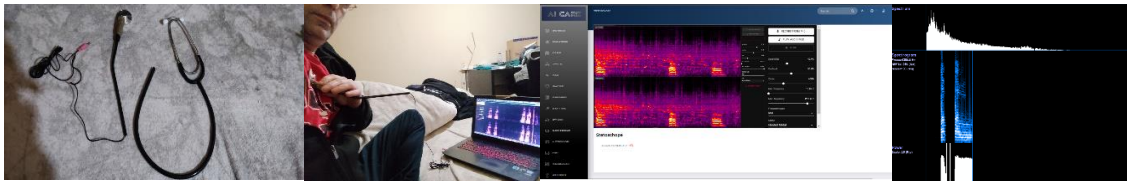


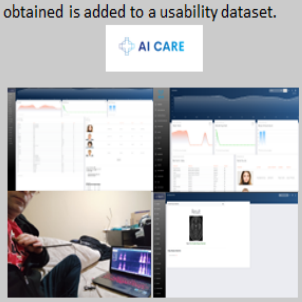
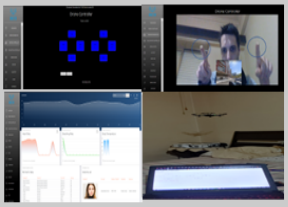
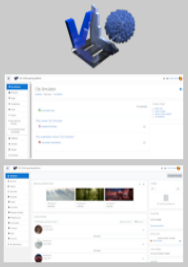
**Figure 74.** Use of a stethoscope and a microphone With XJR to connect the audio to the web application and demonstration via 2 online spectrograms.

# Chapter 5 – Test Analysis, Results and Validations

5

The 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 are based on the results and specific hardware was required to perform the tests such as a stethoscope, a pulse blood pressure monitor, an oximeter, a smart watch, a drone with camera and an IR thermometer.

**Table 3.** Required material for testing purposes.

| **Developed Softwares and Acquired Hardwares used for testing** | | | |
|---|---|---|---|
| Developed Softwares | AI Care – Secondary Care analysis (Spectrogram of the stethoscope results, eye gaze and X-Ray analysis ). The information obtained is added to a usability dataset.<br>  | Droctor – Measurement of vital signs of a patient via the drone camera. The information obtained is added to a usability dataset.<br>  | Vel – Based on Moodle that records all the information of the users and provides logs for Statistical reporting. The information obtained is added to a usability dataset.<br>  |
| Acquired Hardwares | Stethoscope and microphone<br>  | 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.<br>  | 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.<br>  |
| | 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<br>  | VR Glasses Smartphone WPS, 3D, Bluetooth with remote. 3D Virtual Reality Glasses for Smartphone. Compatible with Smartphones 4.7" - 6.5". Field of View: 95º, Adjustable Focus and Distance. Smartphone Requires Gyroscope Sensor. Velcro Headband with Adjustable Measure. Bluetooth controller, 195x115x135mm.<br>  | 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.<br>  |
| | 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.<br>  | 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.<br>  | Drone 720p Ryze by DJI Tello. Flight time: up to 13 min Image transmission distance: 100m. HD 720p broadcast Intel processor. Box Contents Accessories: Battery, Propellers, Propeller Guard, Compartment. Compatible with remote controls and virtual reality devices. Maximum speed of 8 m/s.<br>  |

## 5.1 User Interface Comparison

During the tests, was noticed that for the interface made mainly in NodeJS with a video chat where the doctor can communicate with the user, the comprehension level, the interaction and the time to successfully complete the tasks was notoriously higher, because the feedback and the errors are detected on real time making the process of reaching the objectives more efficient. Concerning the interfaces with motion controllers for hand, body and eye gaze, these showed the best results for users with certain disabilities like visual, auditory among others and the level of interest from the users was high, because it is not a common technology and some of the participants were using for the first time. Concerning the first objective it was noticed, that while playing a game the user is at a rest state allowing to use the chosen parameters and for the first research question, was concluded that a video chat can make the process of obtaining vital signs easier because the instructions can be provided on real time.

## 5.2 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 is possible to measure the distance of the face from the camera during readings.

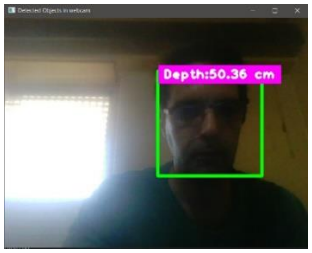



**Figure 75.** Measuring distance from camera to face.

**Table 4. 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 5. Quantitative evaluation results (time to completion in seconds)**

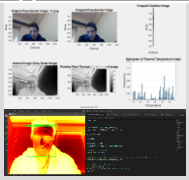
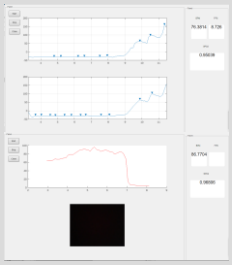
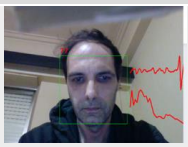
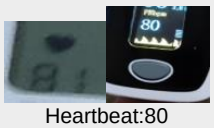
| Testers | Time taken | Standard deviation |
|---|---|---|
| **tester 1** | 14 | 0.416667 |
| **tester 2** | 16 | 1.583333 |
| **tester 3** | 10 | 4.416667 |
| **tester 4** | 12 | 2.416667 |
| **tester 5** | 19 | 4.583333 |
| **tester 6** | 13 | 1.416667 |
| **tester 7** | 10 | 4.416667 |
| **tester 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.

**Figure 76.** Performing the tests with doctors.

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 6.** 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 centigrades | >90% |
| **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 | >98% |
| **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 (SaO2). SaO2 is the percentage of oxygen that blood carries (in red blood cells) compared to its maximum carrying capacity on arteries. |  SpO2: 96% |  SpO2: 96% | Oximetry: oxygen saturation ≥ 95%. | >96% |
| **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. | >99% |
| **Respiratory rate** | The respiratory rate is the number of breaths per minute. |  12 | 12 | Respiratory rate: 12 to 18 breath per minute. | >99% |
| **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 the second research question and the second objective was noticed a proximity of the results obtained by the developed applications with the values from the medical devices, concerning 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.

## 5.3 Tests and Results Concerning the Secondary Care Analysis Used

The binary classifiers for the medical images can be measured via several processes. The confusion matrix allows to measure the performance of an algorithm and a ROC curve was also used.

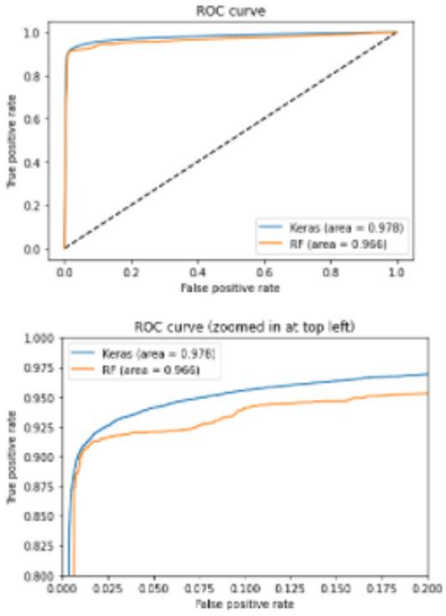



**Figure 77.** ROC analysis.

The area under a receiver operating characteristic (ROC) curve, abbreviated as AUC, is a single scalar value that measures the overall performance of a binary classifier presenting values close to 98%. For the stethoscope, two different spectrograms were used, both by using free open source code provided from the Massachusetts Institute of Technology (MIT) that showed high sensitivity to variations of the sound.

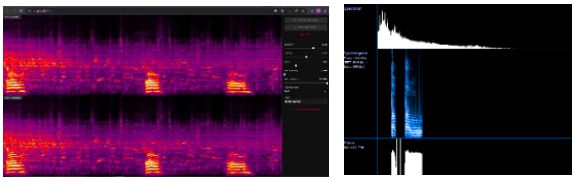


**Figure 78.** The two spectrograms used.

Concerning objective 3 and 4 and research questions 3 and 4, the accuracy values obtained from tests of the artifacts developed were high.

## 5.4 Usability Tests

The fifth objective and fifth research question 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.

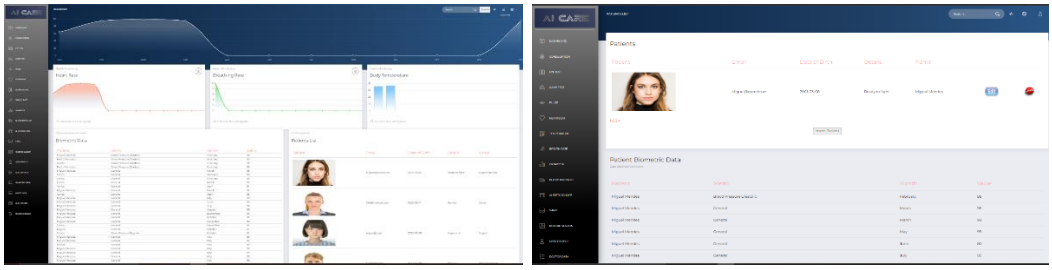
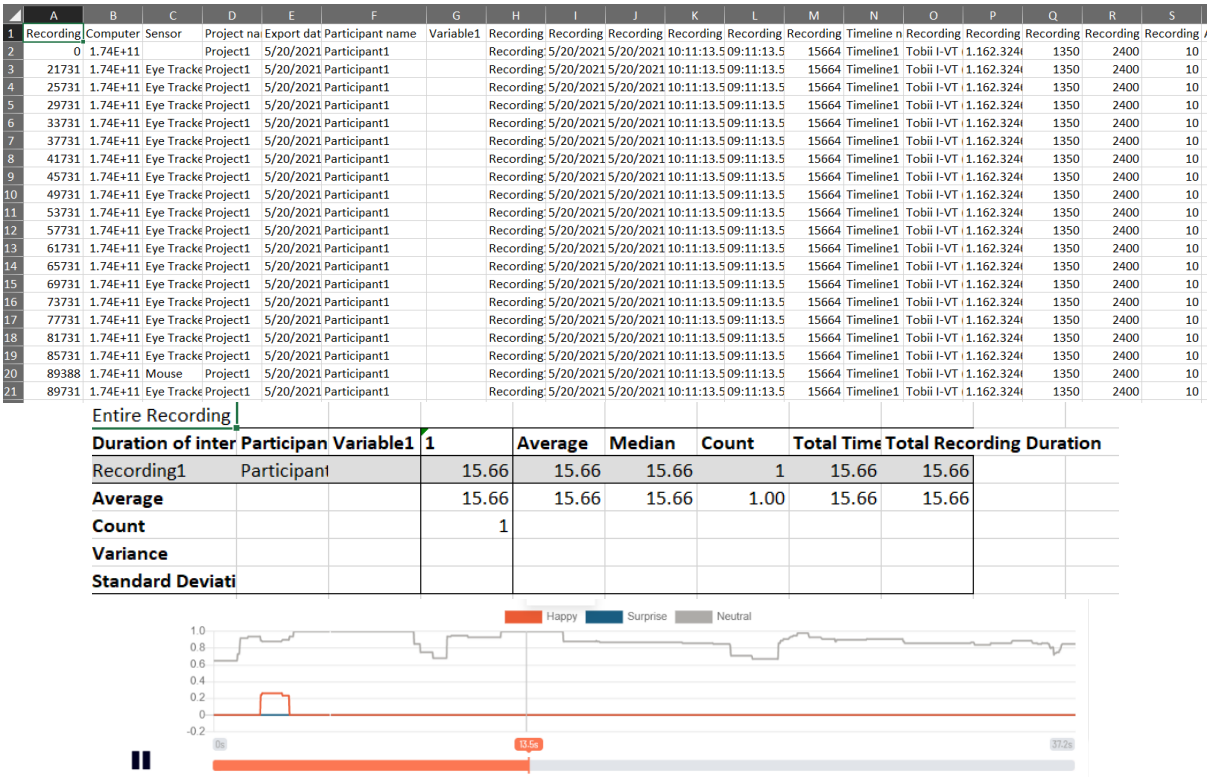


**Figure 79.** Storing the vital signs for different users concerning different time frames.

Eye tracking was used to analyze the reaction of the users while interacting with the system. Camera calibration is required to use this type of test, where the person being diagnosed must look at the points shown on the screen so that the system is able to record and measure the current position of the eyes. Via NodeJS the system is able to interact with the eye movement. WebGazer.js allows to do visual tests.



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Recording | Computer | Sensor | Project na | Export dat | Participant name | Variable1 | Recording | Recording | Recording | Recording | Recording | Recording | Timeline n | Recording | Recording | Recording | Recording | Recording |
| 2 | 0 | 1.74E+11 | | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 3 | 21731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 4 | 25731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 5 | 29731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 6 | 33731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 7 | 37731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 8 | 41731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 9 | 45731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 10 | 49731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 11 | 53731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 12 | 57731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 13 | 61731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 14 | 65731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 15 | 69731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 16 | 73731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 17 | 77731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 18 | 81731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 19 | 85731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 20 | 89388 | 1.74E+11 | Mouse | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |
| 21 | 89731 | 1.74E+11 | Eye Tracke | Project1 | 5/20/2021 | Participant1 | | Recording | 5/20/2021 | 5/20/2021 | 10:11:13.5 | 09:11:13.5 | 15664 | Timeline1 | Tobii I-VT ( | 1.162.324( | 1350 | 2400 | 10 |

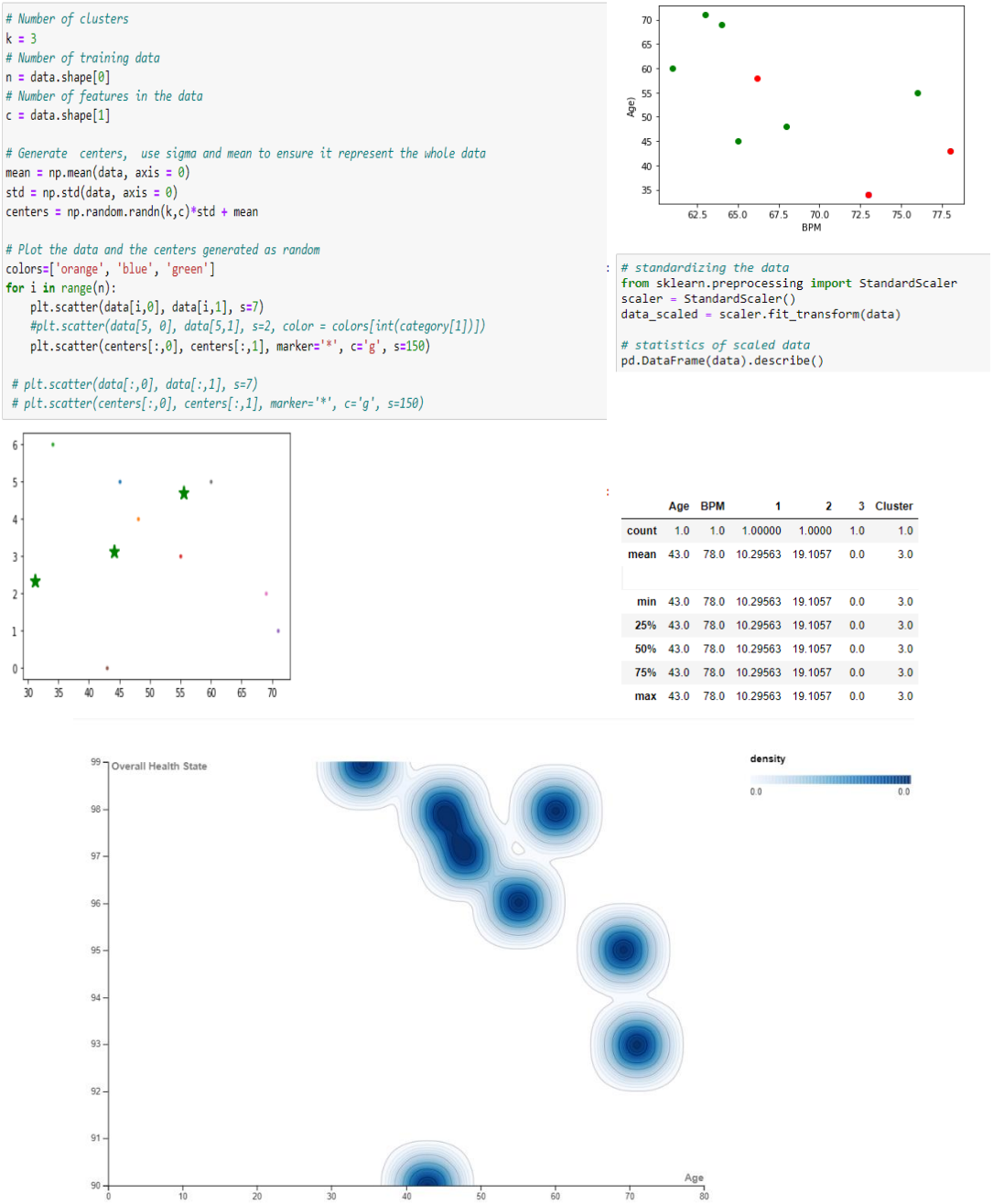
Entire Recording

| Duration of inter | Participan | Variable1 | 1 | Average | Median | Count | Total Time | Total Recording Duration |
|---|---|---|---|---|---|---|---|---|
| Recording1 | Participant | | 15.66 | 15.66 | 15.66 | 1 | 15.66 | 15.66 |
| **Average** | | | 15.66 | 15.66 | 15.66 | 1.00 | 15.66 | 15.66 |
| **Count** | | | 1 | | | | | |
| **Variance** | | | | | | | | |
| **Standard Deviati** | | | | | | | | |



**Figure 80** Eye Gaze statistics for different time intervals.

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. By using the ML Clustering process via the unsupervised algorithm K-means it is notorious that the general health state is higher for younger ages and the BPM tends to decrease while ageing.




```
# Number of clusters
k = 3
# Number of training data
n = data.shape[0]
# Number of features in the data
c = data.shape[1]

# Generate  centers,  use sigma and mean to ensure it represent the whole data
mean = np.mean(data, axis = 0)
std = np.std(data, axis = 0)
centers = np.random.randn(k,c)*std + mean

# Plot the data and the centers generated as random
colors=['orange', 'blue', 'green']
for i in range(n):
    plt.scatter(data[i,0], data[i,1], s=7)
    #plt.scatter(data[5, 0], data[5,1], s=2, color = colors[int(category[1])])
    plt.scatter(centers[:,0], centers[:,1], marker='*', c='g', s=150)

 # plt.scatter(data[:,0], data[:,1], s=7)
 # plt.scatter(centers[:,0], centers[:,1], marker='*', c='g', s=150)
```

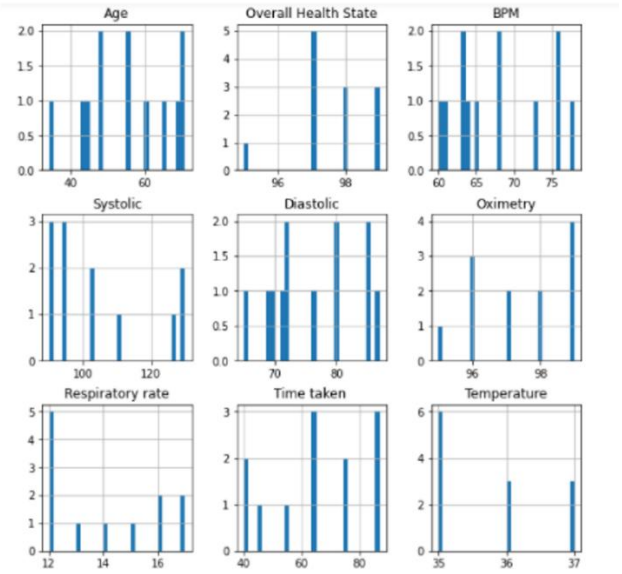
```
# standardizing the data
from sklearn.preprocessing import StandardScaler
scaler = StandardScaler()
data_scaled = scaler.fit_transform(data)

# statistics of scaled data
pd.DataFrame(data).describe()
```

| | Age | BPM | 1 | 2 | 3 | Cluster |
|---|---|---|---|---|---|---|
| count | 1.0 | 1.0 | 1.00000 | 1.0000 | 1.0 | 1.0 |
| mean | 43.0 | 78.0 | 10.29563 | 19.1057 | 0.0 | 3.0 |
| min | 43.0 | 78.0 | 10.29563 | 19.1057 | 0.0 | 3.0 |
| 25% | 43.0 | 78.0 | 10.29563 | 19.1057 | 0.0 | 3.0 |
| 50% | 43.0 | 78.0 | 10.29563 | 19.1057 | 0.0 | 3.0 |
| 75% | 43.0 | 78.0 | 10.29563 | 19.1057 | 0.0 | 3.0 |
| max | 43.0 | 78.0 | 10.29563 | 19.1057 | 0.0 | 3.0 |

**Figure 81.** Analysis using the K-means algorithm on the usability dataset.

Via the ML Classification process using the supervised algorithm K-nearest (KNN) it was noticed that the Overall Health State is higher on younger people and the BPM on adult women is higher than men.




| | 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 |

```
: from sklearn.metrics import classification_report
  from sklearn.metrics import confusion_matrix
  pred = knn.predict(X_test)
  print(confusion_matrix(y_test, pred))
  print(classification_report(y_test, pred))

  [[0 1]
   [0 2]]
                precision    recall  f1-score   support

            95       0.00      0.00      0.00         1
            97       0.67      1.00      0.80         2

      accuracy                           0.67         3
     macro avg       0.33      0.50      0.40         3
  weighted avg       0.44      0.67      0.53         3
```

**Figure 82.** Analysis using the KNN algorithm on the usability dataset.

Throw the test results, it is possible to conclude that there is a better overall health status for lower ages.

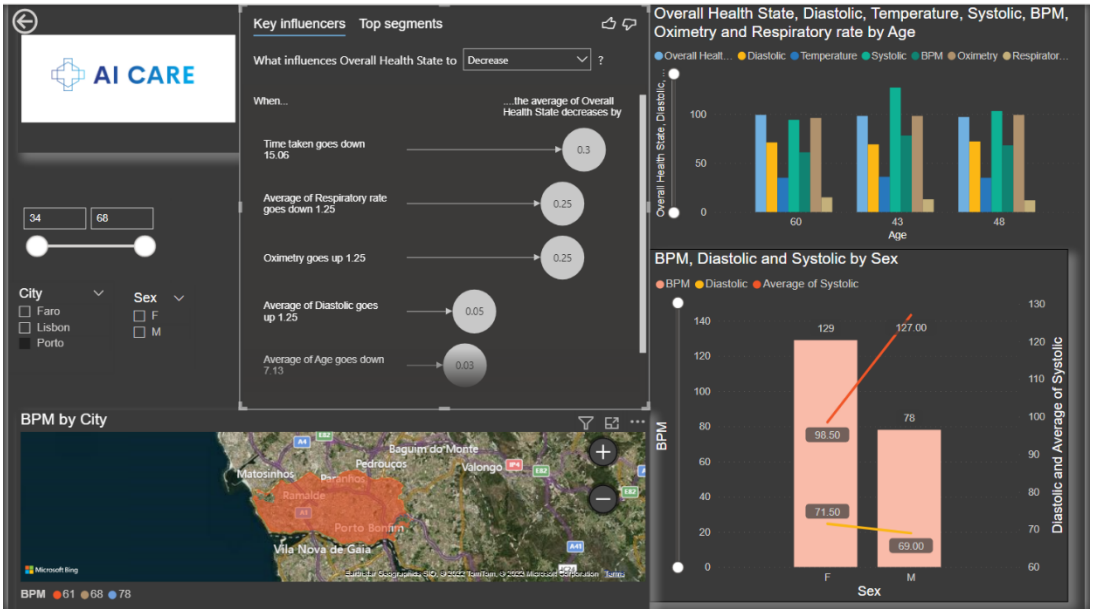



**Figure 83.** Reporting results via Power BI.

## 5.4 Churn prediction with machine learning via Azure

A dataset was generated based on the tests with the users. This data was treated and after used a train model to apply one of the ML algorithms for prediction in this case the two class decision forest. The score model allows to see how the model was predicted.

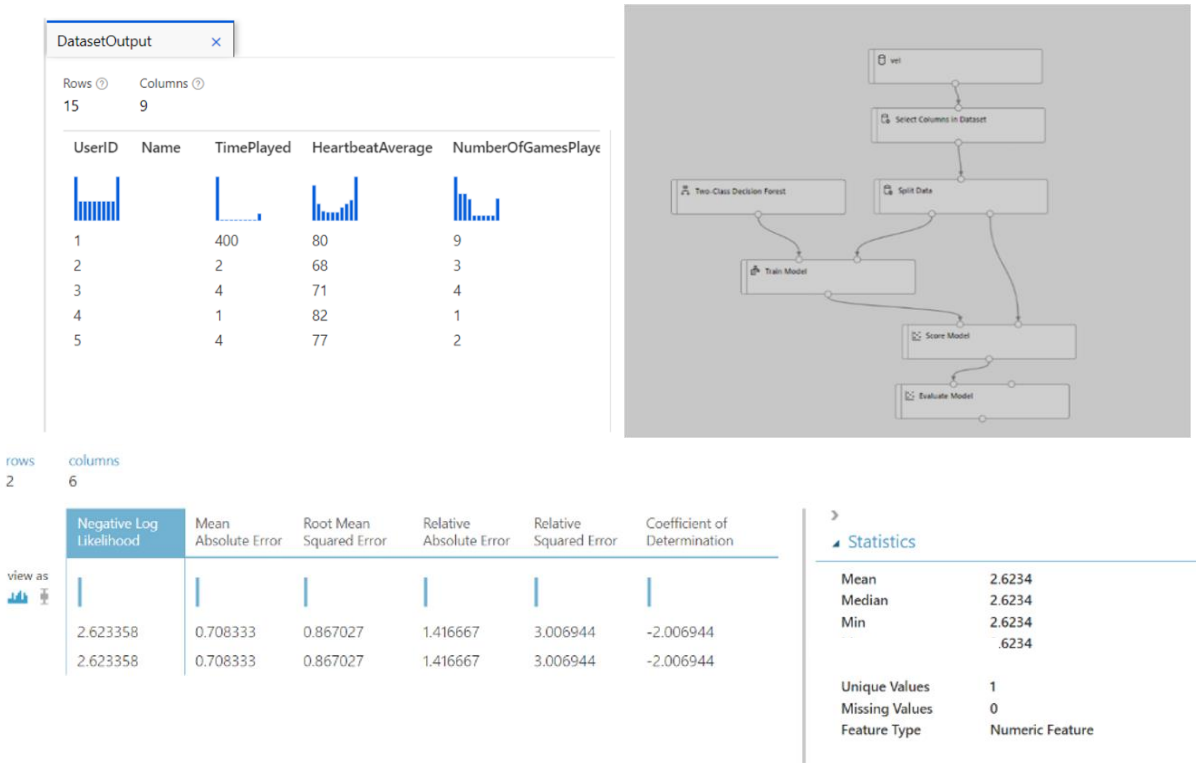



**Figure 84.** Treatment of the datasets to make predictions with Azure ML and statistics.

# Chapter 6 – Conclusions and Future Research

6

In this dissertation was proposed 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 allowed to perform the desired functionalities and provide an innovative concept of online consultations. The development process was described an tests were performed to validate the solution proposal in cause. The research took in consideration several sources of information and many articles of other researchers were analyzed in order to study the problem in cause, for some cases was possible to obtain the accuracy level between the values obtained by the algorithms and the values obtained by medical devices or by using mathematical calculations. Answers to the research questions:

Research question 1: Which of the three mentioned types of user interfaces can make the process of obtaining vital signals during gameplay more efficient? The interface with video chat presented the higher results in several aspects like time to perform the tasks, effectiveness of the results when compared with physical results and levels of interaction and satisfaction. Research question 2: 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 Open CV 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. Research Question 3: 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. Research Question 4: 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. Research Question 5: How can an application be developed to 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.

Possible futuristic researches 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 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.

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