How Augmented Reality can help surgeons and patients

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Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Acknowledgments

After so many years of studying, it is good to feel an accomplished era and a final work that I believe and I'm proud of. However, we live in a community, and I am perfectly aware of the importance of having several vital people beside me.

I want to start from the beginning and thank my amazing family for all the support, education and love that made me who I am today. I was taught the importance of being humble and knowing how to recognize my mistakes, which I always have in mind.

My friends, for the all good times, for their friendship, good advices and spirit of fellowship these past years. They were a key part of my academic path. I will never forget them, and definitely, they will be very important in my future.

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Abstract

Augmented Reality (AR) technology refers to any technology that ”augments” the user’s visual perception of their environment perceived as natural parts. By displaying in real-time texts, graphics, audios and other virtual enhancements, an immersive experience is created. Therefore, AR integrates and adds value to the user’s interaction with his physical surroundings. In the last decades, AR technology’s advances made it attractive, and consequently implemented in diverse areas. Its medical application is increasing due to the numerous benefits it can add.

This thesis describes all steps taken to implement an AR system in medicine, which primarily focuses on developing an ecosystem for hospitalized patients. It aims to improve the patient’s well-being through self-assessments to facilitate his monitoring, and alleviate the fact of being hospitalized in isolation by exploiting AR technology.

To structure the architecture of our application, we inquire healthcare professionals about which features to prioritize and questions to create a complete self-assessment evaluation. Our results suggest that this application is ready to be published since the feedback from the validation and System Usability Scale (SUS) questionnaires were excellent. This application SUS score was 88.43.

Keywords

Augmented Reality; Mobile Augmented Reality; Real World; Self-assessment; System Usability Scale; Virtual Reality;

Resumo

A Realidade Aumentada (RA) refere-se a qualquer tecnologia que ”aumenta” a percepção visual que o utilizador tem sobre o seu ambiente real. Ao sobrepor objetos virtuais em tempo real, é criada uma experiência imersiva em todos os sentidos. Assim, a RA integra e adiciona valor à interação que o utilizador tem com o seu ambiente físico. Nas últimas décadas, os avanços da tecnologia de RA tornaram-na atrativa, e consequentemente foi implementada em diversas áreas. A sua utilização na medicina está a aumentar devido aos inúmeros benefícios que acrescenta.

Esta tese descreve todas as etapas realizadas para implementar um sistema de RA na medicina, em que tem como o seu principal objetivo desenvolver um ecossistema para pacientes hospitalizados. Pretende melhorar o bem-estar do paciente, por meio de auto-avaliações e assim facilitar seu acompanhamento, e, ainda, aliviar o fato de estes estar hospitalizado em isolamento, explorando a tecnologia RA. Para estruturar a arquitetura da nossa aplicação, questionámos profissionais de saúde sobre quais funcionalidades priorizar e que perguntas utilizar para desenvolver uma auto-avaliação completa.

Os nossos resultados sugerem que esta aplicação está pronta para ser publicada, uma vez que o feedback dos questionários de validação e usuabilidade (*System Usability Scale (SUS)*) foram excelentes. O resultado do questionário SUS, desta aplicação, foi de 88,43.

Palavras Chave

Realidade Aumentada; Realidade Aumentada Móvel; Mundo Real; Auto-avaliação; System Usability Scale; Realidade Virtual

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List of Acronyms

2D Two-dimensional

3D Three-dimensional

API Application Programming Interface

AR Augmented Reality

DW Digital World

GUI Graphical User Interface

HMD Head-mounted Display

JSON JavaScript Object Notation

MAR Mobile Augmented Reality

ML Machine Learning

MR Mixed Reality

NRS Numerical Rating Scale

PSS Product and Service Systems

PV Percentage Validation

RW Real World

SDK Software Development Kits

SUS System Usability Scale

UI User Interface

UX User Experience

VAS Visual Analog Scale

VE Virtual Environment

VFX Visual Effects

VR Virtual Reality

1

Introduction

Contents

”Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution.”

Albert Einstein

1.1 Introduction

Evolution is a driving force of Humanity existence. We create technology to fill a void and need, become more efficient, mainly because we can. Over the last years, the growth of technology has been exponential, in such a way that there is a fundamental disconnect between the wealth of digital data available to us and the physical world in which we apply it [7]. While our environment is Three-dimensional (3D), the digital data remains confined to Two-dimensional (2D) devices and displays. Traditionally, the difference between the virtual and real world was the contrast between identity and body. Thus, Augmented Reality (AR) was born.

Augmented Reality (AR) is an enhanced version of the Real World (RW) achieved through digital data (e.g. models or sounds), creating an immersive experience for all senses. AR can place 3D digital models into the real environment by tracking features points and accurately meshing the real world. AR is also interactive in real-time, being able to respond to the user inputs in real-time. These three main features [8–11] create an illusion on a person’s perception of the real world, not as a simple display of data but through blending digital data, which are perceived as natural parts of an environment.

In medicine and healthcare, digital technology transformed unsustainable healthcare systems into sustainable ones, improved the relationship between medical professionals and patients and provided cheaper, faster and more effective solutions for diseases.

1.2 Motivation

Augmented Reality (AR) is becoming more and more present. Its inclusion in the clinical environment is increasing due to the numerous benefits it can add.

Our motivation is to make a difference in patients’ lives and helping to improve the patient condition by developing a Mobile Augmented Reality (MAR) [12] application focused on patients and healthcare professionals. MAR applications are gaining popularity since nowadays everyone has a mobile device, enabling people to explore AR technology. Although mobile devices are more constrained computational wise than traditional computers, they have multiple sensors that can be used to develop more sophisticated MAR applications [13].

An additional motivation came by the end of 2019, which marked everyone’s life. The COVID-19 virus changed everything, our habits, behaviours and priorities. Isolation and ”social distancing” converted our way of living, while physical relationships were severely limited. While these restrictions may be crucial to mitigate the spread of this disease, they had consequences for social and mental health [14].

This pandemic also affected healthcare professionals' work due to the lack of a timely preparation and available resources.

Hospitalized patients' well-being has suffered, with their ability to move around and to received visits being restricted. AR technology can help to alleviate the possible stress that hospitalized patients are subjected to.

In this dissertation, we developed a Mobile Augmented Reality (MAR) application in the field of medicine, which has as its primary focus the development of an ecosystem for the patient. Allowing patients to carry out self-assessment about their condition and enabling them to explore AR features to end the monotony caused by their isolation are the main features in this MAR.

The developed system focuses on hospitalized paediatric patients, a population especially vulnerable to the constrained and isolation scenario. Nevertheless, the prototype serves as a staring point for further improvements and future developments aiming to expand the target population segments.

1.3 Objectives

Implementing this MAR application and considering the reasons to do so, this application aims to:

- Improve the well-being of hospitalized children.
- Decrease and alleviate the mental health issues caused by the monotony of being locked and isolated.
- Enable patients to express themselves creatively, improving the hospitalization period;
- Evaluate patients' condition, and therefore complement the regular evaluation made by healthcare professionals;
- Educate patients about their clinical condition and which cares to take.

1.4 Organization of the Document

This thesis comprises six chapters, which are organized as follows:

Chapter 1 provides a brief description of the work motivation and goals.

Chapter 2 starts by providing the necessary background knowledge and overviews the related work.

Chapter 3 describes the methodology followed to implement the proposed MAR application. A questionnaire was prepared to understand what medical features would be more important to include, in the eyes of the medical community. This chapter ends with the proposed MAR application architecture.

Chapter 4 explains how the proposed MAR application was implemented. The chapter is organized into two parts, first describing the front-end" and then the "back-end" implementation.

Chapter 5 provides an evaluation of the proposed methodology and the application's implementation. Another questionnaire was created for this purpose, following the main ideas of a System Usability Scale (SUS).

Chapter 6 summarizes the achieved results, presents conclusions, and discusses directions for future work.

2

Background

Contents

This chapter surveys the current state-of-the-art in Augmented Reality (AR) technology. It starts by presenting a characterisation of what is understood by Augmented Reality (AR), enumerating its main properties and ends by describing different implementations of AR systems at many diverse sites.

2.1 Augmented Reality

In the early 1990s, the need arose for the development of AR systems. Thomas P. Caudell, a scientist and researcher, realized that interpreting instructions from an assembly team took too much time to construct the famous Boeing 747 aircraft. He ended up naming the term Augmented Reality.

2.1.1 Definition and Framework of AR Technology

With the evolution of time, the technology of AR systems has evolved in such a way that the major surveys papers [8–11] defines AR system as any system that successfully follows the following functionalities:

- Must combines Virtual Reality (VR) contents with a real environment.
- Must be register in 3D.
- Must be interactive in real-time (i.e. live) interaction.

The primary functionality of AR is how components of the Digital World (DW) blend in the perception of a person's RW, not as a simple display of data but through the integration of immersive sensations, which are seen as part of our reality. The second functionality means that an AR system should track the position of objects and register them in the representation of the 3D space. This functionality enables the virtual components to appear fixed in the RW. The last functionality is essential so that the computer system, from the AR system, can generate interactive graphics to respond to the user input in real-time. AR enhances real-world environments with additional virtual information.

By the characteristics that define AR, we can conclude that AR is complementary to immersive VR. Augmented Reality is a variant of Virtual Environment (VE) / VR technology. Virtual Reality is a simulated experience where the user cannot see the natural world, placing him into a totally synthetic environment. In contrast, Augmented Reality is the composition of Virtual Reality into the RW, when the surroundings are predominantly real.

Table 2.1: Virtual Reality and Augmented Reality technology requirements. [6]

	Virtual Reality	Augmented Reality
Scene Generation	requires realistic images	minimal rendering okay
Display Device	fully immersive, wide field of view	non-immersive, small field of view
Tracking and Sensing	low accuracy is okay	high accuracy needed

Overlapping information can be either constructive (such as AR, which complements and enriches the real world with virtual texts, images and objects) or destructive (such as VR, where the virtual information completely overwrites the real-world information). VR has the ability to create the impossible since it creates immersive simulations computer-generated. AR has the potential to modify the environment as it morphs the mundane, physical world into a colourful, visual one by projecting virtual pictures and characters through an AR system.

Figure 2.1: Comparison of Virtual Reality with Augmented Reality. [1]

The concept of Mixed Reality (MR) was first defined in 1994 by Paul Milgram and Fumio Kishino as anywhere between the real and virtual world, and MR continuum which is a taxonomy of the combinations virtual and real elements can combine (Fig. 2.2) [6]. MR is a blend of physical and digital worlds, unlocking natural and intuitive 3D human, computer, and environment interactions.

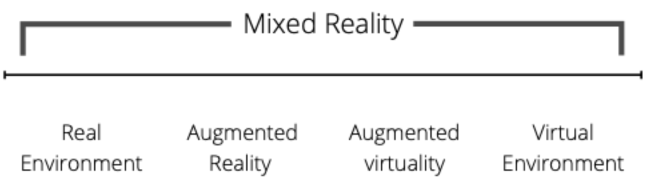

Figure 2.2: The reality-virtuality continuum.

In the past decades, the use of computers has increased exponentially. Interactions between computers and environments are now possible thanks to these new technologies, advancements in sensors and increase processing power. When joined with interactions between humans and computers and between humans and environments, MR experiences are created (Fig.2.3).

The fundamental goal of an AR system is to complement the user's view of the real world with additional 3D computer-generated virtual objects and text that coexist in the same world view. Ideally, the user has the perception of the virtual objects as blending naturally with parts of the real space. This technology has been growing the last few years, and it is only going to get bigger as AR are becoming accessible to everyone who has a smartphone.

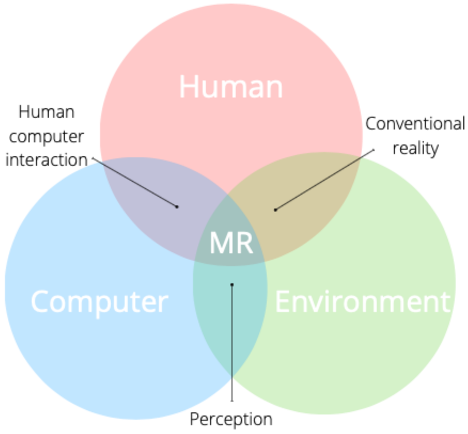

Figure 2.3: The interactions between computers, humans and environments. [2]

2.1.2 Historical Overview

Although AR technology has only aroused more interest and investment in recent years, the technology itself has been around for a few years. Before it became popular, people already tried to live experiences different from reality (e.g. using a kaleidoscope to see different patterns and colours to create an optical illusion). In the subsection above, we already mention important dates about AR life. The beginning of AR dates back to Ivan Sutherland's work in the 1960s. In 1966, he invented the first Head-mounted Display (HMD). In 1968, Sutherland implemented the first prototype of an AR system into the HMD to present 3D graphics. Figure 2.4 shows Sutherland's head-mounted display, which was "so heavy that it had to be suspended from the ceiling, and the formidable appearance of the device inspired its name—the Sword of Damocles" [15].

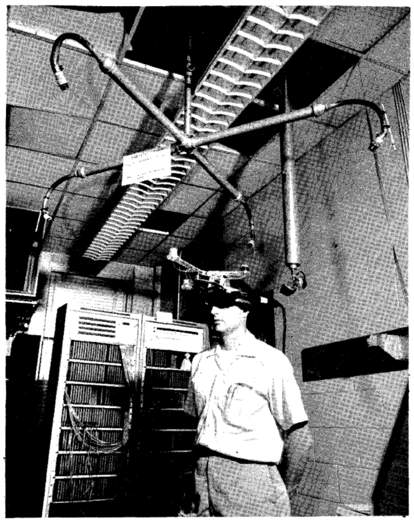

Figure 2.4: First AR system prototype authored by Ivan Sutherland in 1986. [3]

However, only in the 1990s has there been enough work developed to refer to AR as a research field. In 1990 Thomas P. Caudell was trying to find the most efficient way to help workers implement wire harness bundles. So, he developed an AR system, which led him to publish the first academic paper with the term "Augmented Reality". This research was where the term Augmented Reality was invented. Since then, AR's growth and progress were remarkable, enabling key features such as tracking, display and interaction. From the mid-90s, with the interest growth on this technology, more tools were developed and were explored interaction techniques, usability and design theory.

Nowadays, with the new advances in technology, an increasing amount of AR systems and applications are produced, which promises to revolutionise AR technology. As we become more and more dependent on our mobile devices, the quest for augmented reality will begin to rise since anyone can now develop an AR system. Even though people think of AR as a "high tech", AR is already very present. The face filters in Instagram launched in 2018 (Fig.2.5), and the Pokemon Go game released in 2016 (Fig.2.6) are both powered by AR. If we see the amazing evolution AR technology has had since its invention, we can only expect it to take off and soar to new heights.

Figure 2.5: Example of an Instagram AR filter.

Figure 2.6: Example of Pokemon Go's AR mode.

2.2 Applications of AR Systems

In the early age of Augmented Reality (AR), it was defined to such a degree that it demanded the use of a Head-mounted Display (HMD), which can be critical to various fields [8]. With Augmented Reality (AR) evolution, we do not restrict it to any particular display technology since it can be applied to all senses. We can classify displays for viewing the merged virtual and real environments into the following categories: (i) head-worn, (ii) handheld, and (iii) projective.

Augmented Reality (AR) is used to complement the real world and provide enriching experiences. Through advanced AR systems, the information available becomes interactive and digitally manipulable. It is then expected that AR systems can have numerous applications, including fields such as: entertainment, production and repair industries, medicine, teaching, among many others.

This section gives examples and information on how AR systems can be used on various applications, and then we focus on the medical field.

2.2.1 Production and Service Industry

It was in the production and service industry that the term AR was born. Maintaining manufactured products is one of the most common services in the industry. Modern manufacturing companies are shifting their product focus to a combined Product and Service Systems (PSS) ecosystem. PSS is a new strategy that combines the product and services included in it in a bubble.

Augmented Reality (AR) technology for remote maintenance allows cooperation between the on-site technician and the manufacturer. It is possible to coordinate the registration of the product malfunction via the end-user with the instructions provided by the specialist through an AR system. Thus, maintenance through a PSS allows to reduce operating costs and improve customer satisfaction [16].

Figure 2.7: Example of an AR system in maintenance and repair. [4]

On the other hand, maintenance and assembly instructions can be more easily understood with the help of AR technology. If instructions are available as 3D projections overlaid on the actual product, showing step by step the tasks that need to be performed and how to do them, the instructions will be more explicit, and efficiency will increase.

2.2.2 Education

Every industry has adopted the inclusion of technology in order to take the best income. Unfortunately, today's teaching continues to be exercised just as it was in the former times. Our educational institutions are frustratingly outmoded in terms of teaching students since very little has changed. Humans learn best by doing, not by reading or listening to lectures. The more immersive experience students can have, the more influential will be the learning experience. In this sense, AR appears as an emerging technology that promises to make ”educational immersion” available to practically everyone.

These experiments have shown that AR can help students learn more effectively in some situations and have increased knowledge retention relative to traditional 2D desktop interfaces.

In 2007, Andreas Dünser and Eva Hornecker [17] studied how AR impacts children reading and book-centric learning. AR was used to overlay interactive 3D digital content on the real book pages (Fig. 2.8. This research shows that AR books could be introduced into an educational setting relatively easily.

In 2017, Ying-Shao Hsu, Yuan-Hsiang Lin and Beender Yang [18] explored the possibility of em-

Figure 2.8: Children engaged in interactive sequences.

bedding AR in authentic inquiry activities to contextualise students' exploration of medical surgery. The results showed that the students had positive perceptions of the AR lessons and simulators after completing the two lessons, because AR triggered motivation and engagement.

2.2.3 Medicine

In recent days, AR applications in medicine are being vigorously researched with the advances in optics, computer systems, and surgical instruments. AR technology finds a vast range of applications in medicine since it can improve and enhance the user experience. Most research aims at using AR technology for intuitive intraoperative surgical navigation by merging the real operating scene with virtual organs segmented from preoperative data. However, AR technology is now being implemented in all sectors: pre-surgery and teaching, surgery, and post-surgery and treatment. Healthcare professionals can no longer ignore the impact of this technology is changing our daily activities and patient treatment. Since patient histories are now stored as electronic records, healthcare professionals can use AR to view patient's data (e.g. checking previous test results and essential information about the patient), while performing medical acts, even during surgery.

2.2.3.A Pre-surgery and Teaching Applications

Using HMDs or other AR display devices, AR technology promises new methods to visualise three-dimensional anatomical structures for meticulously preoperative planning purposes (Fig. 2.9). Studies suggest that being able to prepare medical operations with more detail shorter operative times and increased accuracy are expected [19, 20]. AR allow surgeons to perform a patient-specific surgery in a 3D environment as if it is a real one. The 3D virtual surgery provides the surgeon with a better understanding of the surgical procedure, allowing him to perfect his technique.

According to the glossary of medical education terms, from AMEE, medical education is "the process of teaching, learning and training of students with an ongoing integration of knowledge, experience, skills, qualities, responsibility and values which qualify an individual to practice medicine" [21]. Augmented Reality (AR) has the potential to provide powerful, contextual, and situated learning experiences, as well as to aid exploration of the complex interconnections seen in information in the real world.

Figure 2.9: Designs of authentic inquiry activities with tables and surgery simulators [5]

It allows the user to observe any part of the body using the corresponding 3D model, which can be overlaid with the real body images being captured by a camera. AR thus enables the digital manipulation of data, creating an opportunity to teach in a different, interactive and practical way. It ends up being more economical since the same human model can be used numerous times, updated at any time and can correspond to real cases. Virtual instructions could remind a novice surgeon of the required steps without the need to look away from a patient to consult a manual.

It has been proved that the use of AR is more beneficial, as it promoted increased engagement of medical students [22].

2.2.3.B Surgery Applications

Augmented Reality (AR) can allow doctors to provide guidance, help, and support with valuable information during a surgical operation. It can support the rehearsal or discussion of the operation, for which a realistic virtual version of the patient's organ is helpful in an actual surgical operation. Surgeons are often the earliest adopters of technical tools that can enhance the surgical and patient experience. Surgery support systems is an AR application that assists surgeons in their operations via live overlays. For instance, it can allow a surgeon to visualise unrevealed organs, bones, or veins, contributing to improve surgery efficiency. During the execution of surgery, it is also possible, through object recognition, to project the precise location of the incision points on the lenses of the HMDs. The main advantage of AR is that the surgeon is not forced to look away from the surgical site as opposed to standard visualisation techniques [10].

The work reported in [23] evaluates the accuracy of AR navigation for the intraoperative mandibular angle osteotomy with other interventional techniques. The AR system used is based on computer vision, i.e. when detecting and tracking a fiducial marker (see Fig. 2.10), the system overlays the Real World with a virtual model. During surgery, a virtual image was projected through the AR display so that the surgeons could determine the incision point (see Fig. 2.11).

Figure 2.10: Fiducial marker use to enable the AR system to display the 3D model in the correct position.

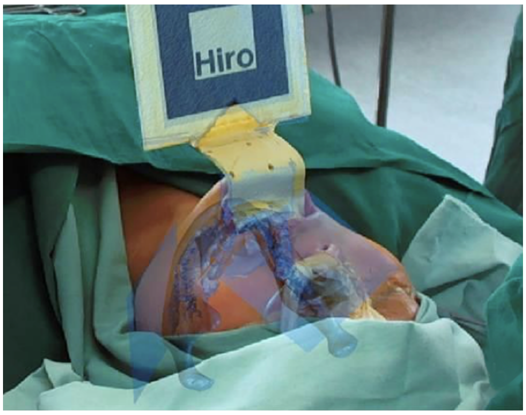

Figure 2.11: Visualization of the AR system during surgery

2.2.3.C Post-surgery and Treatment Applications

Augmented Reality (AR) is not just useful for surgery but also other treatment modalities. In the hospital or nursing home, doctors or nurses on their rounds of visits to the patients could get important information about them. Thanks to immersive training systems and a better comprehension of the ongoing procedure, AR applications in medicine increase patient safety and decrease recovery time [24]. It can also be advantageous in educating the patient as well as for patient care. AR technology can also be used to nudge the patient in real-time for healthy habits and medication adherence.

Remote virtual rehabilitation aroused growing interest in the last decades, and its role has gained importance following the recent spread of the COVID-19 pandemic. AR applications in recovery produce an effect of gamification, making telerehabilitation viable [25]. An immersive experience will increase patient engagement. Remote virtual technologies allow the delivery of high-quality care at reduced costs. Another application in medical treatment is augmented reality exposure therapy which is digitally assisted psychotherapy to enhance post-traumatic stress disorder (PTSD) treatment, by increasing a patient's sense of presence during exposure therapy [26].

2.2.3.D Current Issues

A medical AR system typically performs three tasks: camera or instrument tracking, patient registration, and creation of preoperative planning data. Additionally, in the field of medicine, especially in surgery, accuracy and reliability are vital. According to [27], there are still some technological and architectural problems associated with AR based healthcare, and figure 2.12 summarises those limitations. The security and privacy involved with medical data requires that data must be completely encrypted and protected. The lack of specialised Application Programming Interface (API)s, frameworks and appropriate libraries can be another issue. Displays and tracking related issues arise from the fact that the most convenient display is HMD for surgery. It allows the surgeon to have both hands free. However, HMDs are not always very accurately placed and can lead to depth perception limitations. Because of the complexity of the AR technology the medical staff has to be retrained to use it.

The introduction of this technology cannot be forced, since, despite being relatively easy to handle, it is a complex technology that implies some change in the current *modus operandis*. Therefore, it ends up being better internalized and manipulated if the request to use it comes from the clinical workers. A possible less intrusive approach is found in teaching, where it is possible to practice using an HMDs in practical classes to familiarize users. During surgery, the creation of the post of a shadow surgeon (it can either be a student or an assistant) who uses HMDs can help to assimilate the AR framework.

To have an AR system that works precisely and effectively while remaining in service for a long time is relatively difficult. In order to fix the precision and tracking problem, the HMDs should include some focal features, such as multifocal plane display, varifocal plane display, computational multiplayer display, integral imaging-based display. The implementation of such an AR system can however have a high development cost.

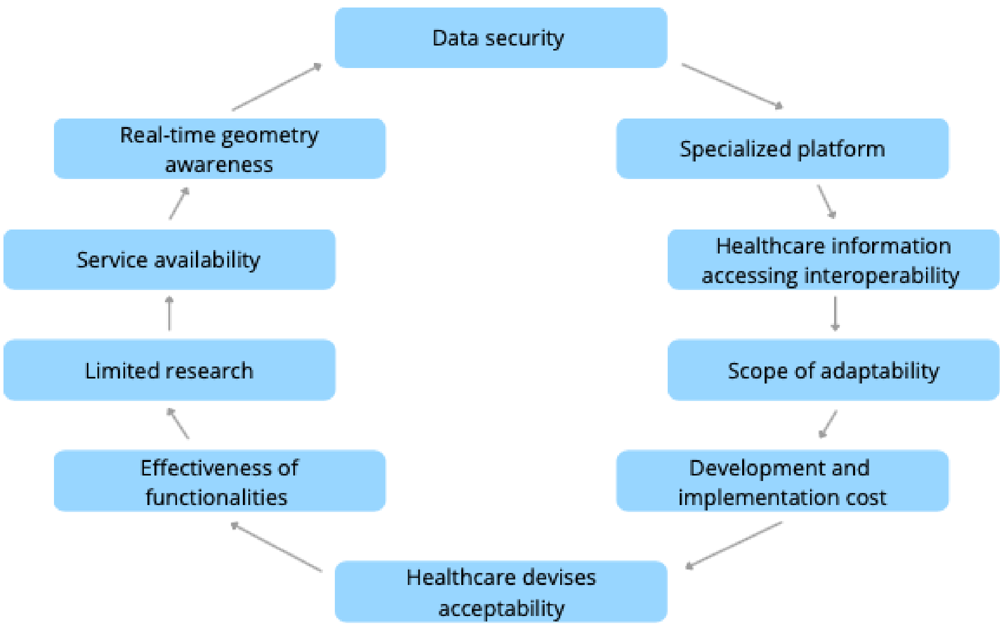

Figure 2.12: Current issues of AR-based healthcare discipline.

3

Methodology and Proposed Solution

Contents

The demand for Augmented Reality (AR) technology integrated into the clinical environment is increasing due to the numerous benefits it can add. This chapter describes the main steps followed for the development of a mobile augmented reality application in the field of medicine. More specifically, the AR application developed aims to improve the quality of life of hospitalized children.

3.1 General Description

The application developed in the context of this dissertation has as its primary focus the development of an ecosystem for the patient. It aims to improve the patient's well-being, alleviating the fact of being hospitalized in isolation, by exploiting AR technology to let the patient express himself creatively, contributing to help improve the quality of the hospitalization period. The application also allows the user to inform caregivers about the patient's well-being and medical condition evolution through medical assessments, consequently facilitating their monitoring. The use of augmented reality also allows the inclusion of therapeutic exercises in a subtle way, thus promoting patient compliance.

Unfortunately, we live in a difficult period of humanity, where the virus COVID-19 makes relationships with others impossible. It can be unsafe to say hello to a person, give a hug, or even shake hands without running the risk of contracting the virus. This way of living had a very negative impact on people's psychology and even more on children, whose interaction with others is essential for their development. For children who have been hospitalized during this period, it has been even worse. They live locked in quarantine in their rooms without seeing other people except their parents and health professionals. Since parents cannot always be with their children 24 hours a day, medical supervision has become more significant. Lamentably, hospitals have been overcrowded, and health workers often feel drained and overwhelmed, lacking sleep, overworking hours, and don't always have the best working conditions.

Due to the limited time available for developing this application, a prioritization had to be made and the decision was to focus on improving the following aspects:

- Well-being of hospitalized children, who suffer the problem of being restricted to the same limited space every day.
- Verification of patient's conditions, making it more regular, using technology to overcome the shortage of staff.

To address these issues, this thesis proposes the creation of an augmented reality mobile application for the usage of hospitalized pediatric patients, therefore creating the ecosystem where the user can provide information about his condition and also be able to have fun with AR features.

The proposed application is composed of two main conceptual modules: (i) Medical Evaluation and (ii) Enjoyment, allowing users to carry out a self-assessment of their condition, and reinvent the spaces they inhabit, respectively.

The medical evaluation module of the application aims to question and assess the patient's status regularly. To do this, the patient must carry out a specific self-assessment similar to the regular evaluations made by health professionals to patients.

The enjoyment module of the application aims to help alleviating the possible stress that hospitalized pediatric patients are subjected to. For example, through AR technology, the user can decorate and diversify the space in which he is staying.

To be able to develop an application that fulfills the goals listed above, a first step was to prepare a questionnaire, addressed to health professionals, to validate the problems identified and to prioritise the modules to be developed. The collected answers were essential to design the proposed MAR application.

3.2 Application Requirements Identification

To identify the requirements for the application to be developed, the input from the medical community is determinant, as these professionals deal with the identified problems in first hand. It was therefore decided to carry out a questionnaire to understand what application modules would be more helpful to better assist patients and, consequently, also the health professionals.

This questionnaire is intended to evaluate the key issues that allow a patient to carry out an accurate self-assessment to complement the daily evaluation carried out by health professionals. It is also essential to understand if it is interesting to provide information about the clinical condition to the patient and which pain assessment tests to use. Additionally, find out which methods and features improve to reduce stress levels using AR technology.

3.2.1 Questionnaire for Health Professionals

A questionnaire directed to healthcare professionals was prepared. It was written in Portuguese, as it was addressed to Portuguese healthcare professionals. A total of 36 people answered, covering the following professions:

- Student of Medicine or Nursing - *Estudante de Medicina ou Enfermagem*;
- General Formation Intern - *Interno de Formação Geral*;
- Specialist Training in Pediatrics / Pediatric Surgery - *Interno de Formação Específica de Pediatria / Cirurgia Pediátrica*;
- Internal Specific Training from another area - *Interno de Formação Específica de outra área*;
- Specialist in Pediatrics / Pediatric Surgery - *Médico Especialista de Pediatria / Cirurgia Pediátrica*;
- Specialist Physician in another area - *Médico Especialista de outra área*;
- Nurse - *Enfermeiro*;
- Therapist - *Terapeuta*;
- Non-specialist doctor - *Médico Não Especialista*.

The distribution of the respondents professions is summarized in Fig. 3.1.

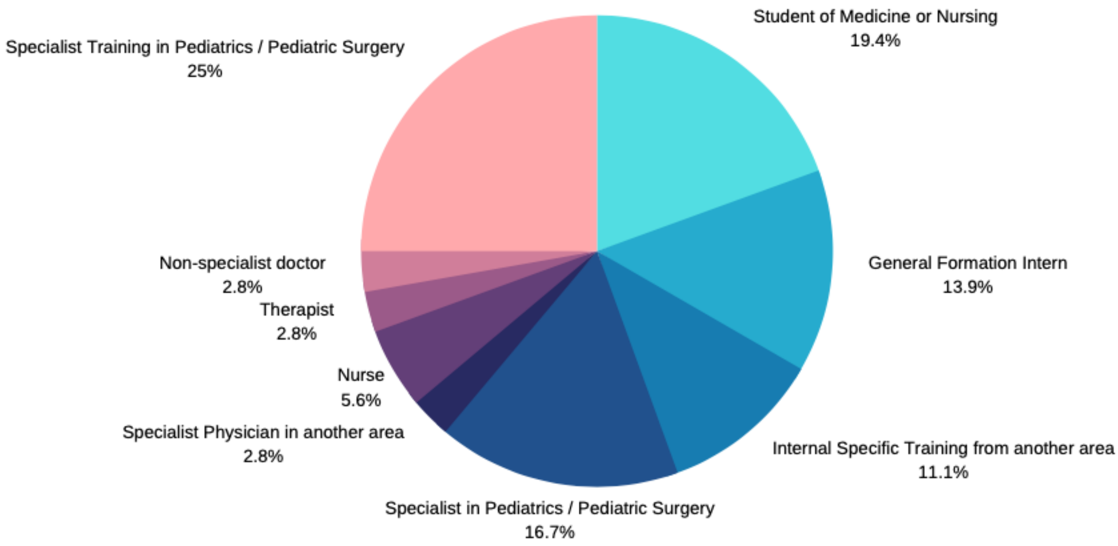

Figure 3.1: Distribution of professions of healthcare personnel that answered the questionnaire.

3.2.2 Requisites concerning Design and Implementation

This section discusses some of the collected information that will help to design and create an effective application. Both the medical evolution and the enjoyment modules are discussed.

3.2.2.A Medical Evolution Module

This part of the application aims to carry out a short and specific self-assessment for the patient to complement the assistant physicians in their daily clinical evaluation. Nevertheless, this self-assessment is not intended to replace the daily evaluation carried out by health professionals, as the personal interaction with a child allows gathering more reliable and complete information. For instance, it is necessary to understand from what age a child can correctly answer questions posed using a mobile application. We also evaluated a series of questions that would be crucial to create an accurate daily self-assessment for an inpatient, where the patient will have to answer questions about the experienced pain, such as its intensity, location, type and duration. A quick way to indicate where the user feels pain is to use a 3D model of the human body to select the pain region.

For patients in paediatrics, several tests can be used to assess the patient's condition. According to the guidelines of the Portuguese *Direção-Geral de Saúde*, although there are instruments for the various pediatric ages and clinical situations, there is no universally accepted solution. Given the patient's age, the Portuguese *Direção-Geral de Saúde* recommends the use of the following pain assessment scales [28]:

Under 4 years old or children unable to verbalize:

- FLACC (Face, Legs, Activity, Cry, Consolability);

Between 4 and 6 years old:

- FPS-R (Faces Pain Scale - Revised);

- Wong-Baker scale faces;

From 6 years old:

- VAS (Visual Analog Scale)[1];
- NRS (Numerical rating scales)[2];
- FPS-R (Faces Pain Scale - Revised);
- Wong-Baker scale faces;

Since the pain assessment tests are different depending on the age of the children, we decided to initially create two different base models - one for younger children and one for older children. Our initial proposal was for model A to include children between 6 and 12 years old and model B between 13 and 17. At the age of 6, children learn how to read in school, becoming available to do a self-assessment. At the age of 13, children became teenagers when usually it is a time for growth spurts.

3.2.2.B Enjoyment Module

The second module of the application contains the features that allow the user to be entertained and consequently reduce the stress levels caused by their clinical condition and hospitalization. Since patients are locked in their room, AR technology allows them to break this monotony, for instance by virtually decorating their room in any way they want, consequently making hospitalization a more stimulating experience. Another hypothesis of incorporating this technology is in physical therapy recovery by promoting more dynamic exercises, as mentioned in the previous chapter. The inclusion of school exercises, especially for children hospitalized for long periods, to keep up with the main curricular contents, could also be proposed in a captivating way.

3.2.3 Questionnaire Analysis

3.2.3.A Medical Evolution Module

By analyzing the answers given by health professionals, we were able to define priorities and outline the best strategy to address the problems mentioned at the beginning of this section. When validating that a hospitalized child has difficulty providing accurate answers in a medical evaluation (see Fig.3.2), we learn that a child should be over six years old (see Fig.3.3) to provide an accurate self-assessment about his condition. This information is in line with our initial guess since, at the age of six, children attend the first year of school and learn how to read, becoming able to do the test by themselves.

Initially, due to the answers given, a series of crucial questions were obtained to create a base model for a short but accurate self-assessment test. These were the questions asked and their results (see Fig.3.4):

- Q.1: Region of the body where the patient feels pain or discomfort - 97.2%;

[1] The Portuguese translation was used in the questionnaire - EVA
[2] The Portuguese translation was used in the questionnaire - EN

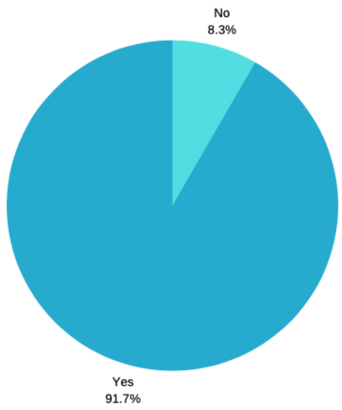

Figure 3.2: Hospitalized children have difficulty providing accurate answers in a medical evaluation.

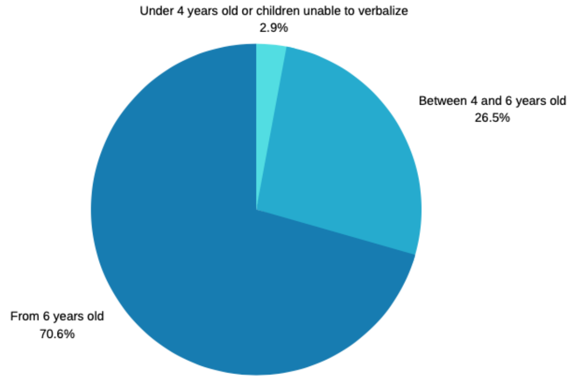

Figure 3.3: Age a child is capable to provide an accurate self-assessment about his condition.

- Q.2: The duration of pain or discomfort - 77.8%;
- Q.3: The type of pain or discomfort - 83.3%;
- Q.4: The intensity of pain or discomfort - 97.2%;
- Q.5: If the pain or discomfort is due to movement or position - 88.9%;
- Q.6: If the patient managed to sleep well - 75.0%;
- Q.7: What is the patient's state of mind - 61.1%.

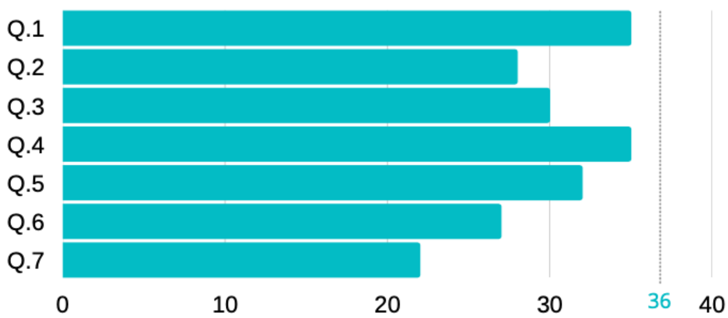

Figure 3.4: Results of the crucial questions to create a base model for a child's self-assessment medical test.

Since there is a variety of pain assessment scales and each one is more suitable according to the child age, we decided to divide the solution into two models:

- Model A - for children between 6 and 12 years old;
- Model B - for children from 13 until 18 years old.

According to the educational stage, Model A corresponds to primary education (from 1º grade until 6º grade) and Model B to secondary education (from 7º grade to 12º grade).

For Model A, the instrument selected to evaluate the pain scale is the Wong-Baker scale faces - illustrated in Fig.3.5 - with 80.6% of the healthcare professional choosing it (see summary of results in

Fig.3.6). This scale shows a series of faces ranging from a happy face at 0 (or ”no hurt”) to a crying face at 5, which represents ”hurts like the worst pain imaginable”. Based on the faces and written descriptions, the patient chooses the face that best describes their pain level.

Figure 3.5: Wong-Baker scale faces.

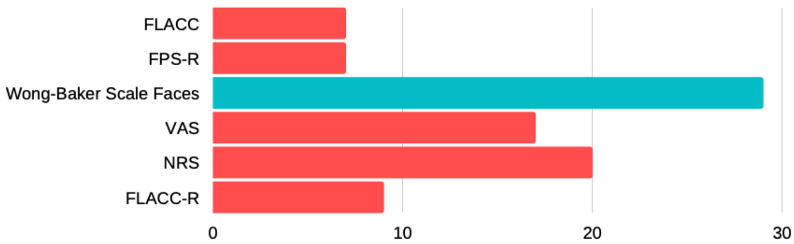

Figure 3.6: Pain assessment scales votes for Model A.

For Model B, since the children's age is more advanced, the pain assessment instrument chosen was Numerical Rating Scale (NRS) - illustrated in Fig.3.7, with 88.9% of people voting for it (see summary of results in Fig.3.8). The NRS is a segmented numeric version of the Visual Analog Scale (Visual Analog Scale (VAS)) in which a respondent selects the whole number (0–10 integers) that best reflects the intensity of his/her pain. The 11-point numeric scale ranges from '0' representing one pain extreme (e.g. ”no pain”) to '10' representing the other pain extreme (e.g. ”pain as bad as you can imagine” or ”worst pain imaginable”).

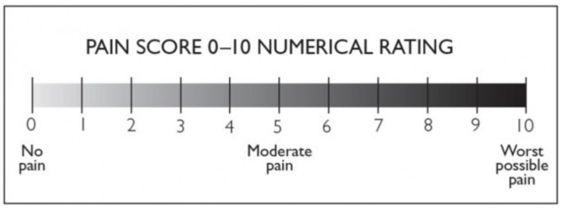

Figure 3.7: Illustration of the numerical rating scale.

The additional inclusion of a 3D human model in the self-assessment test when the user is locating where he feels pain or discomfort was also validated, consequently making identification easy and accessible (see summary of results in Fig.3.9).

Regarding the information to be made available about the patient's condition, it was found that the most critical information to be displayed would be his clinical picture (with a 72.2% agreement) and cares for him to take during hospitalization (with a 75% agreement) in a language suitable for the patient (see summary of results in Fig.3.10). Model A should use a simpler language, while Model B can be more detailed. We found that the availability of the consequences of someone's clinical status (30.6%) and

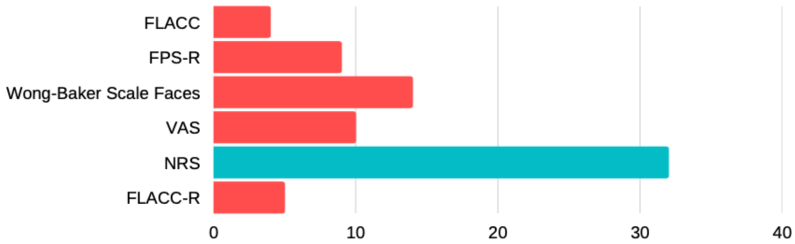

Figure 3.8: Pain assessment scales votes for the Model B.

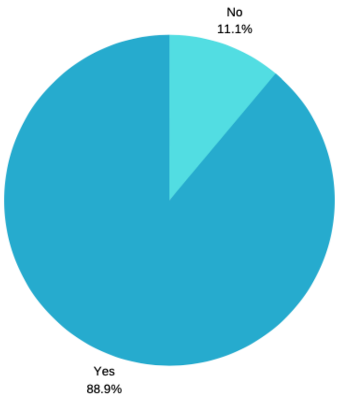

Figure 3.9: Handle of a 3D model of the human body to indicate a site of pain or discomfort.

the expected duration of the hospitalization (38.9%) would not be beneficial, as it could have negative consequences and could cause false expectations.

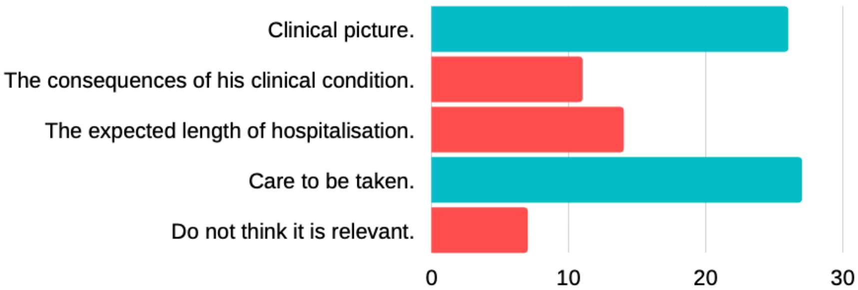

Figure 3.10: Responses to the inclusion of information about the patient's condition.

3.2.3.B Enjoyment Module

The responses collected (86.1%) agreed that sick children suffer from stress during hospitalization and that an entertainment feature would help attenuate the experience, as can summarized in the figure below. These feature correspond to the Enjoyment module.

The desired functionality to be included in the application, concerning the enjoyment module,was validated by healthcare professionals, including the following components:

1. Ability to virtually decorate the space in which the child is hospitalized (88.9%).

2. Inclusion of daily challenges, to create a more stimulating experience (77.8%).
3. Integration of school exercises, notably to address long-term hospitalizations, so that children do not get behind in their studies (100%).
4. Creation of a schedule, to help the patient establish a routine and remind him to take the self-assessment tests (100%).

The questionnaire also collected opinions about the interested of developing an extra module exploiting the use of AR technology to guide physical therapy exercises. In this way, it is expected to increase the motivation of patients, especially children, to generate a more pleasant and harmonious environment for the exercises and seek to promote the effectiveness of the treatment.

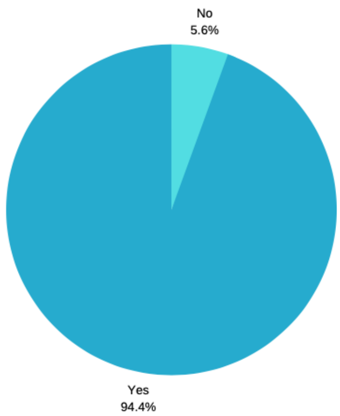

Figure 3.11: Validation of the idea of developing a feature that uses AR in physical therapy exercises.

3.3 Proposed Mobile AR Application Architecture

This section presents the architecture of the mobile AR application implemented to assist hospitalized children (inovAR app). inovAR is an ecosystem that allows the user to make regular self-assessments, provides medical advice to the patient and gives children the opportunity to change their hospital room's perspective, by incorporating virtual elements to enhance their perception of reality.

This inovAR application is composed by two main parts: a ”front-end” and a ”back-end”, where the term ”front-end” refers to the user interface, while ”back-end” refers to the server, application and database that work behind the scenes to deliver the appropriate information to the user. The architecture of the proposed application is presented in Fig. 3.12. In this architecture a user can enter requests via the mobile AR application's interface. After verification of the input data it is sent to the server, pulling the necessary data from the database, processing the information and sending the obtained results back to the user.

The ”front-end” is divided into two parts: the user's (patient's) interface and the healthcare professional's interface. The patient will have access to the Medical Evaluation and Enjoyment modules. The second part corresponds to the Health Professional's module - where the patient is registered (sign-up), and the self-assessments results may be checked.

The functionalities supported by the mobile AR application are summarized in corresponds to Fig. 3.13. When the application starts there are two options: (i) to select the User's Menu; or (ii) select the Healthcare Professional's Menu, which requires the input of a password, to prevent patients from accessing and possibly unintentionally deleting some of the collected information.

In the Healthcare Professional's Menu, it is possible to: (i) register (sign-Up) a new patient, making that the active user; or (ii) see the available Results from the active patient's Self-assessment.

In the User's Menu, it is possible to choose from: (i) doing the daily self-assessment; (ii) checking the clinical information summary; or (iii) selecting the enjoyment module.

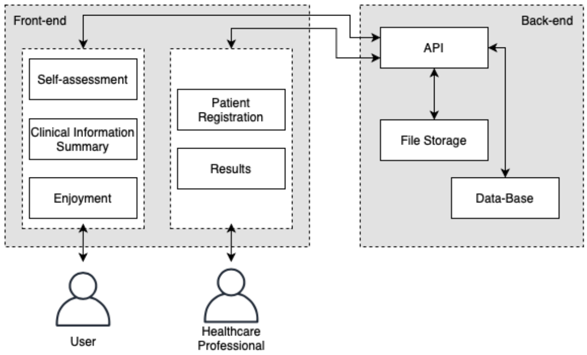

Figure 3.12: Architecture of the proposed mobile AR application.

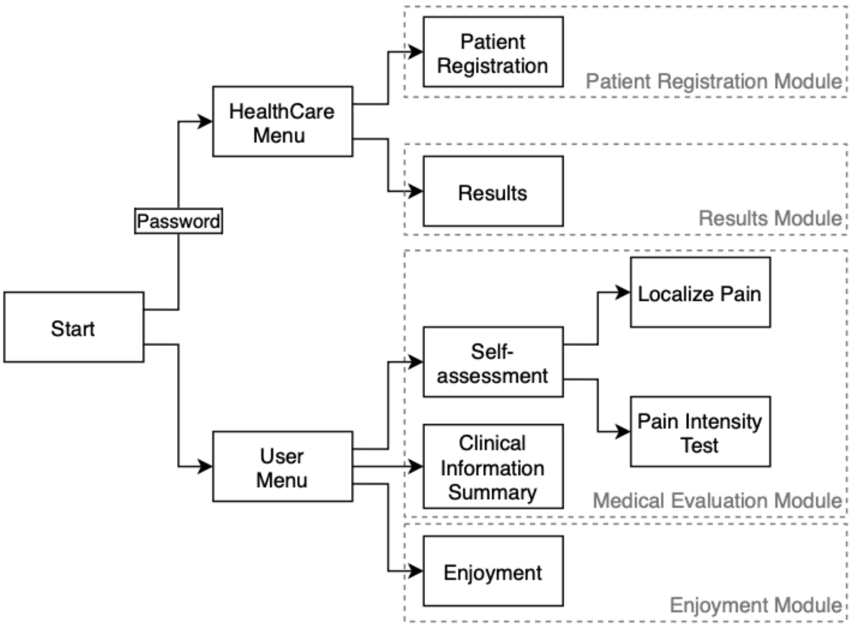

Figure 3.13: Functionality supported by the mobile AR application.

This section presents the framework used for developing the mobile AR application, intending to analyze the design processes.

3.3.1 Medical Evaluation Module

The Medical Evaluation module is composed of the Self-Assessment (see Fig. 3.14) and the Clinical Information Summary (see Fig. 3.15) sub-modules.

As described in Section 3.2.3.A, the daily self-assessment evaluates whether the patient is feeling pain, and indicating where with the help of the display of a 3D human model that allows the patient to click in a body region. Also the pain intensity is registered, according to the chosen pain assessment methodology more suitable for the patients age group, as discussed in Section 3.2.2.A. The application additionally registers if the patient has pain while moving, and which movement causes it, and if the patient was able to sleep or rest. After performing the daily self-assessment the collected information is sent, via email, to the healthcare professional, and is saved in the mobile AR application's file storage to be consulted later, when the healthcare professional consults the Results module.

The Clinical Information Summary sub-module contains the information about the patient that is provided by the healthcare professional when registering the patient into the application, addressing the patient's state and the care to be taken during hospitalization.

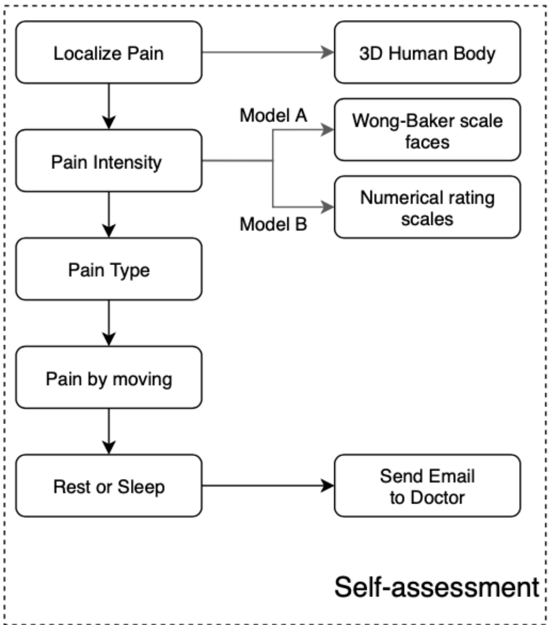

Figure 3.14: Self-Assessment architecture.

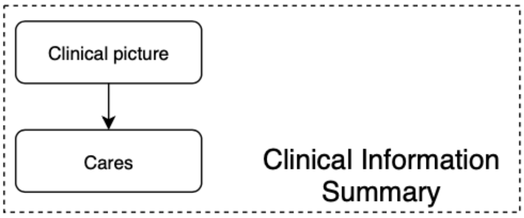

Figure 3.15: Clinical Information Summary architecture.

3.3.2 Enjoyment Module

In the Enjoyment module, the only feature presently implemented concerns the ability to virtually redecorate the space in which the child is hospitalized. The user starts with two options: (i) to create a new map; or (ii) to load and modify a previously created map (see Fig. 3.16). When creating a new map, the user must scan the room, collecting visually salient feature points, to enable the creation of a 3D model of the physical space to be virtually redecorated (Fig. 3.17 shows the the 3D model placed in the real environment and the collected features points as stars). Then, the user can build immersive AR experiences linked to the physical locations of the real environment, with the addition of virtual object models. When saved, all information of which model (scale, orientation and position relative to the available features points), and the collected features points themselves, are stored into the "back-office" database. To load a map, the user must start by capturing images of the surrounding environment, to allow the mobile AR application to match the previously stored features points, and thus to place the previously inserted virtual object models into the same spatial positions as before.

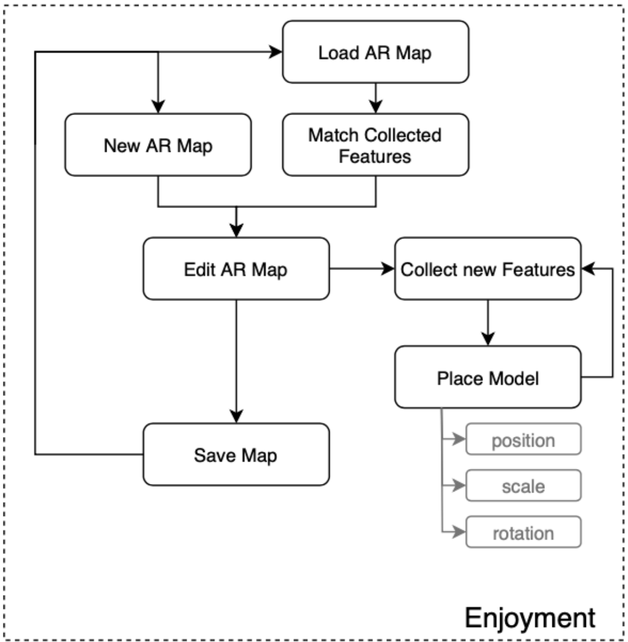

Figure 3.16: Enjoyment module architecture.

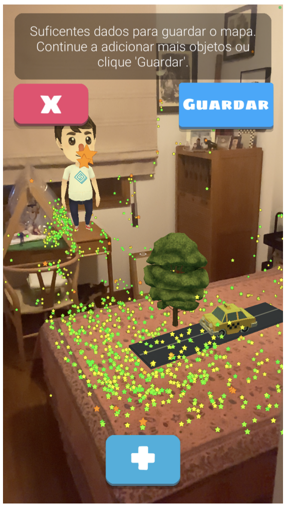

Figure 3.17: Example of a map create with the Enjoyment Module features in the inovAR application.

3.3.3 Patient Registration Module

This module allows the healthcare professional responsible for following a given patient to register him into the mobile AR application - see (Fig. 3.18). This includes providing some essential patient's information, such as the name, age, model (A or B), but also information about the patient's condition and the essential information about the type of care to be taken. Also information about the professional in charge of the patient will be included, the name and email to which the self-assessment results will be sent. Every time a new patient is created, he becomes the active patient in the application.

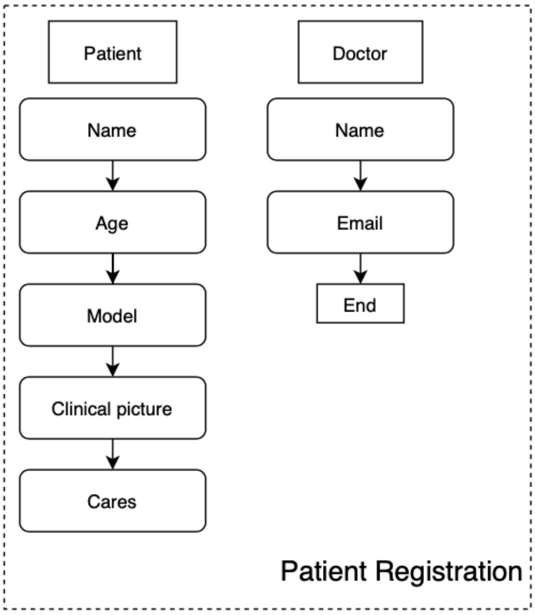

Figure 3.18: Patient Registration architecture.

3.3.4 Results Module

The Results module is where the healthcare professional can see all the self-assessments done by the active patient. When one of the tests is chosen, the information displayed will have the same template as the email sent when the test was executed.

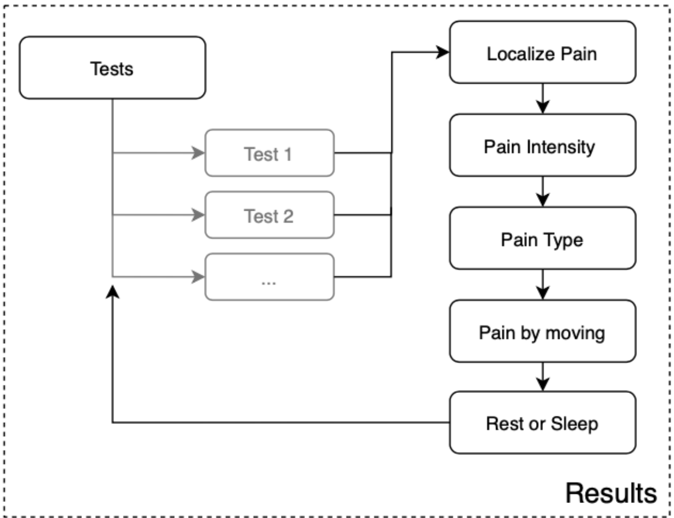

Figure 3.19: Results architecture.

4

Application Implementation

Contents

This chapter details the implementation of the mobile AR application developed in this dissertation, entitled *inovAR*. It specifies the "front-end", focusing on the enjoyment module where AR can be experienced by the user, detailing the reason for choosing the user interface design. It also describes the "back-end", which provides the basis for information storage on the mobile database and for processing using the server.

4.1 Front-end Implementation

The first step to begin the implementation of the mobile AR application, was to choose a suitable application development environment. Unity [29] was chosen for this purpose since it provides a robust ecosystem, with strong cross-platform support. Build once, deploy anywhere, helping the programmer to remain in the same ecosystem while developing a project. That is what makes Unity among the handful prefered engines to develop rich-featured games and applications. Unity is supported by a large community, sharing information, models, and tutorials, which allows a quick adaptation to the development environment. Unity also includes all the required tools to develop an application, without the need for third-party programs, such as the Asset Store and the Unity Reflect Review. The Asset Store [30] allows downloading assets (e.g. 3D/2D models, textures & materials, Graphical User Interface (GUI) and Visual Effects (VFX)), tools (e.g. visual scripting, terrain, AI), and services (e.g. Unity Monotization and Unity IAP (in App Purchases)).

The "front-end" is what a user sees and interacts with. When developing the "front-end" of the *inovAR* application, we designed and constructed the user experience elements. This user experience elements can be divide into User Experience (UX) and User Interface (UI). The terms UX and UI have become inadvertently misused in the mobile app development community. It is nearly impossible to separate one discipline from the other since both are crucial in user engagement for MAR. While the UX is a combination of tasks focused on optimising a mobile app for effective and enjoyable use, the UI design is its counterpart – the look and feel, the presentation, and overall interactivity of a product. The difference between a good and a bad implementation can make significant changes in users' opinions about the application. The fact that the target users of the inovAR application being developed are children makes a good implementation very important.

The inovAR application will be used both by patients, the hospitalized children, and also by the healthcare professionals. Therefore there must be an initial selection of the type of user. This could have been implemented creating two different applications, each with its own UI, but for simplicity of distribution of the application for testing purposes, the present version consists of a single application, which has two buttons to differentiate the types of users - see Fig. 4.1. As the healthcare professional's menu has access to private information, it must be password protected, as illustrated in Fig. 4.2. When the app is executed for the first time, without any registered patient, only the button relative to the healthcare professional's menu is shown. For the registered child to easily understand which button to choose, the button itself will have the children's name written on it, and it has an animation to make it stand out.

Figure 4.1: Welcome interface.

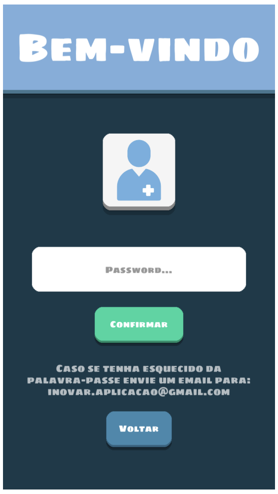

Figure 4.2: Password requirement to enter healthcare professional's menu.

4.1.1 Medical Evaluation Module

As discussed in Chapter 3, the Medical Evaluation module comprises the (i) Self-Assessment and the (ii) Clinical Information Summary components.

(i) Self-Assessment

The implementation of the Self-Assessment sub-module is divided into five parts, as illustrated in Fig. 4.3:

- Locate the body's region where the patient has pain;
- Classify the intensity of the pain (using the Wong-Baker scale for younger children - model A, or a Numerical Scale - model B);
- Select the type of pain that best fits the one experienced by the patient;
- Assess whether the patient has pain when performing any movement (if so, in which one);
- Register whether the patient was able to sleep or rest.

For the patient to locate the region of the body where he feels pain, a 3D human model was created. The 3D model matches the standard body position or anatomical position to increase precision further: the body standing upright, with the feet at shoulder width and parallel, toes forward. Using this standard position reduces confusion. The body regions considered are shown in Fig. 4.4, which were adopted from [31]. To promote clear communication, the peritoneal cavity (abdominal region) was divided into nine regions (see Fig. 4.5), according to [32]. These divisions are marked by two parasagittal and two

Figure 4.3: Self-assessment Evaluation interface.

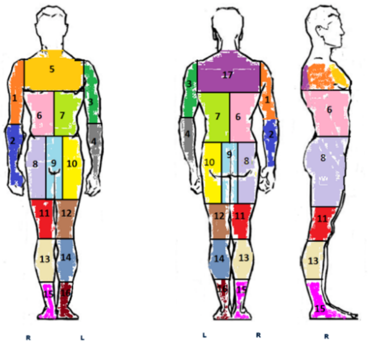

Figure 4.4: Seventeen zones of a human body in a standard position.

Figure 4.5: Nine abdominal regions divisions.

transverse planes centered around the navel. The abdominal divisions should be used in conjunction with other diagnostic approaches to achieve an accurate diagnosis of the patient's condition.

To implement the body model as described, at each region of the 3D model a collider (mesh collider) was placed. Colliders components define the shape of an object for the purposes of physical collisions. The *Raycast* function of Unity's Physics class was used, which allows selecting each region, or deselecting an already chosen one, with the user's input. This method makes the process more straightforward and precise. Also a scroll bar, allowing the rotation of the 3D model, was added to simplify the identification of the body region where the patient experiences pain.

For classifying the pain intensity, both the Wong-Baker faces scale (for model A, see Fig. 3.6) and the Numerical rating scale (for model B, see Fig. 3.8) were implemented . When using the Wong-Baker faces scale implementation, in addition to displaying the faces that represent the levels of pain, we added a short description to help its usage, as illustrated in Fig. 4.7. When using the Numerical rating scale, used by older children, only the value of pain intensity is requested, which is provided by using a scroll bar, as illustrated in Fig. 4.8.

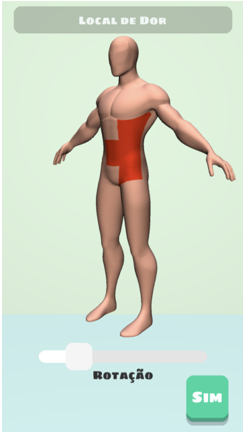

Figure 4.6: Pain region selection interface using a 3D model of a human body.

Figure 4.7: Wong-Baker Faces Scale pain assessment.

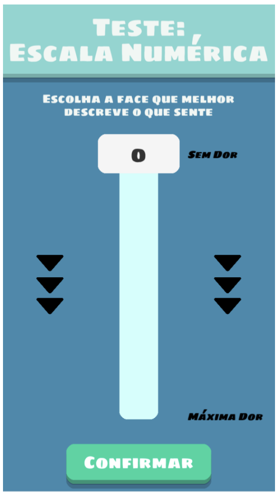

Figure 4.8: Numerical rating scale pain assessment.

To conclude the self-assessment, the user answers the last three questions: what type of pain best resembles his feeling, whether he has pain while moving (if so, which movement causes it), and if he was able to sleep or rest (see Fig. 4.3). At the end of the evaluation, this information is sent to the identified responsible healthcare professional's email and saved in the server's file storage. The type of information that is stored is explained in a later subsection (4.2.1 Mobile Storage).

(ii) Clinical Information Summary

The implementation of the Clinical Information Summary sub-module was relatively simple. It consists in accessing and retrieving the corresponding information stored in the server's file storage, with the patient's information inserted by the responsible healthcare professional when registering the patient. Then, the Unity UI is used to display the clinical information summary, and care recommendations to be following during the hospitalization period. To implement this functionality a UI toolkit for developing user interfaces for games and applications, the GameObject-based UI system, was adopted, which uses Components and the Game View to arrange, position, and style user interfaces.

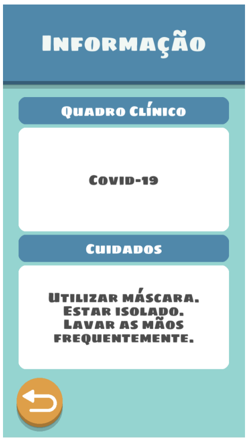

Figure 4.9: Clinical Information Summary interface.

4.1.2 Enjoyment Module

The implementation of the Enjoyment module was the most challenging one. It is in this module that AR technology was implemented. To implement this module using Unity, the first step was to understand which AR tools were available. In particular, there is a feature called AR Foundation that allows working with augmented reality platforms in a multi-platform way within Unity. To use AR Foundation on a target device, separate packages for the target platforms officially supported by Unity are also needed, notably:

- ARCore XR Plugin on Android [33];
- ARKit XR Plugin on iOS [34];
- Magic Leap XR Plugin on Magic Leap [35];
- Windows XR Plugin on HoloLens [36].

Since the inovAR application is expected to be installed in tablets or smartphones, the most relevant AR modules are those required for implementation on Android and iOS devices. There are several differences between ARKit and ARCore Software Development Kits (SDK), in terms of supported features (see Table 4.1), as summarized in the following:

- Google's Android SDK tracks more feature points; it expands the mapped area more quickly than ARKit.
- ARKit detects horizontal and vertical surfaces more accurately than ARCore.

However, the last updates gave ARKit several advantages, such as new tools to handle people occlusion, motion capture and collaborative sessions. We started to focus on developing an application for iOS devices since the only device available to test it was iOS because this thesis was implemented during quarantine due to the virus COVID-19. Nevertheless, instead of using ARkit SDK, we end up using Placenote SDK [37] because:

- Placenote is the only SDK that ships with various open-source sample projects that give developers a fully functional starting point for their apps.

Table 4.1: Features support per platform from AR Foundation.

	ARCore	ARKit	Magic Leap	HoloLens
Device tracking	✓	✓	✓	✓
Plane tracking	✓	✓	✓	
Point clouds	✓	✓		
Anchors	✓	✓	✓	✓
Light estimation	✓	✓		
Environment probes	✓	✓		
Face tracking	✓	✓		
2D Image tracking	✓	✓	✓	
3D Object tracking		✓		
Meshing		✓	✓	✓
2D & 3D body tracking		✓		
Collaborative participants		✓		
Human segmentation		✓		
Raycast	✓	✓	✓	
Pass-through video	✓	✓		
Session management	✓	✓	✓	✓
Occlusion	✓	✓		

- Placenote does not need GPS, markers or beacons for position tracking. Instead, it lets users dynamically scan any space and turn it into a trackable map for positioning digital content.
- Placenote gives complete control over the developer's maps through the online developer portal since it saves all information from a map in a metadata file.

These three reasons helped a lot at the beginning of the development of the Enjoyment module.

At the start of this module, the user can choose between creating a new map (*Novo Mapa*) or loading a previous one (*Carregar Mapa*) (Fig.4.10). In this module, a notification panel (at the top of the device) helps the user in each task because of its complexity. During the loading of this module, the SDK is initialised and the device position is accessed.

4.1.2.A Creation of a New Map

If the user selects the option to create a new map, a new session is started, which means that the device will start to collect key feature points to create a 3D mesh that represents the surrounding environment. These features points are classified between weak and strong, and when visualised, their colour ranges between red and green, respectively. When a plane is recognised, a white reticle will appear (as illustrated in Fig. 4.11).

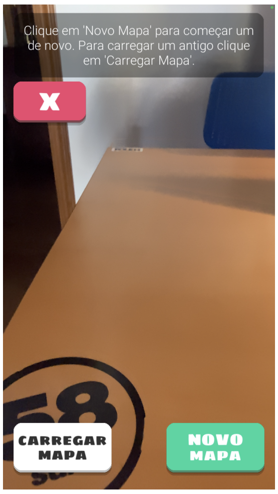

Figure 4.10: Opening scene from Enjoyment module.

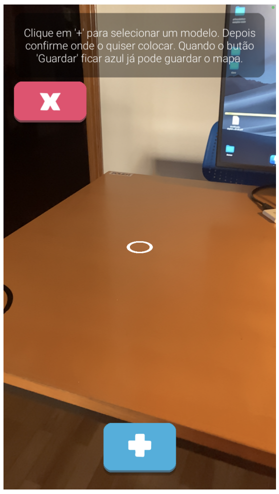

Figure 4.11: Display of the white reticle after SDK recognised a plane.

The user can then choose, from a drop down menu, the 3D model of an object that he wants to place on scene's position indicated by the recticle, by pressing the button '+' that is visible in the graphical user interface. After choosing the model, the user can change his scale, orientation and rotation using the top buttons (shown in Fig. 4.12). Until the model is finally included into the 3D scene, by pressing the button *Sim*, the object's position can be changed by moving or rotating the device. The user can repeat this action to include additional objects into the scene. The application's software will continue collecting feature points, to later be able to recognise the same 3D scene position and place every object's model as specified when creating the map. The user can only save the map after collecting a sufficient number of feature points, that ensures that the 3D mesh representing the scene is above the quality threshold [38]. When the button *Guardar* (save map) is filled (starts grey and ends blue), the map can be saved (see Fig. 4.13). To be saved, the user must enter an identification name to make it easier when later reloading this map. The information from the map and the last GPS position from the device are stored in the Placenote server.

4.1.2.B Loading a Previous Map

In the load map functionality, the first step is searching on the Placenote server, which available maps are associated with, i.e. were created by, the active user. This information is loaded and then a list of the available maps is displayed, as illustrated in Fig. 4.14. The user can select to load or to delete a map.

If the user chooses to load an existing map, the information is loaded and processed, after which a thumbnail showing a part of the map (usually where many feature points were detected) will be shown on the left bottom of the screen, as illustrated in Fig. 4.15. This thumbnail helps the user searching that portion of the 3D scene, so that it gets captured by the camera, to allow pairing the stored 3D mesh to the world space. When matched, all the object models will be placed according to their parameters (position, scale, rotation and orientation) as an example, the object models present in Fig. 4.16 match

Figure 4.12: 3D model selected in process of been placed.

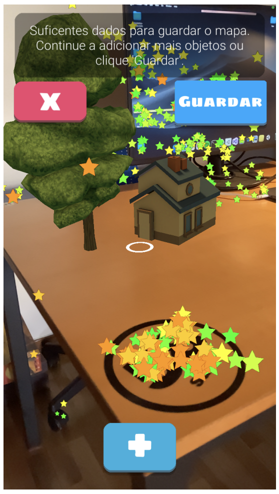

Figure 4.13: Map with enough features points collected to be saved.

those shown in Fig. 4.13. Then, the user can update the map, the same way as when creating a new one, as the enjoyment module architecture shows - see Fig.3.16.

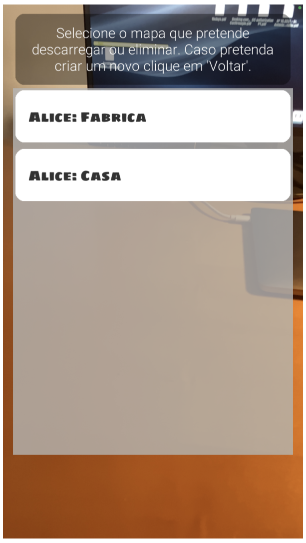

Figure 4.14: Display of all maps found.

4.1.3 Patient Registration Module

The Patient Registration module allows to collect information about the patient. The responsible healthcare professional will register the information about the patient (name, age, self-assessment model, description about the patient's condition and the essential information about the type of care to be taken), and himself (name and email). The interaction component input field is used for this purpose - Fig. 4.17. An input field is a way to allow the user to write a text that can be controlled. For example, the input field associated with the patient age is an integer number (allows only whole numbers to be entered), and the input field associated with the responsible healthcare professional is of the "email address" type (allowing to enter an alphanumeric string consisting of a maximum of one @

Figure 4.15: Thumbnail from the map to be loaded.

Figure 4.16: Map loaded and found.

sign, periods/baseline dots cannot be entered next to each other). This information will be stored in the device. Since each device is associated with only one patient throughout his hospitalization, when a new patient is enrolled, all information from the previous patient (name, age, clinical status,...) should be previously eliminated. This also prevents the device from becoming overloaded after being used by several users.

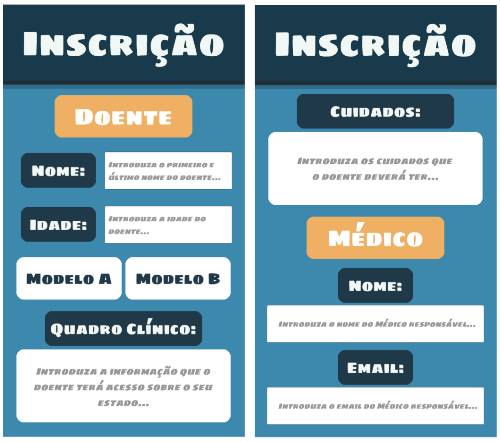

Figure 4.17: Sign-in module interface.

Despite creating two different models for the self-assessment (Model A and Model B), the final decision is from the responsible healthcare professional. So despite asking the patient's age, we also ask which model the patient belongs to.

4.1.4 Results Module

The implementation of the Results module was relatively straightforward. At the start, a list of all the evaluations made is displayed, sorted by date. This information has been stored in the file storage server after each evaluation. After the healthcare professional selects one item to visualise, all the corresponding information is shown, the same way as the email sent at the end of the self-assessment.

Figure 4.18: Results module main menu.

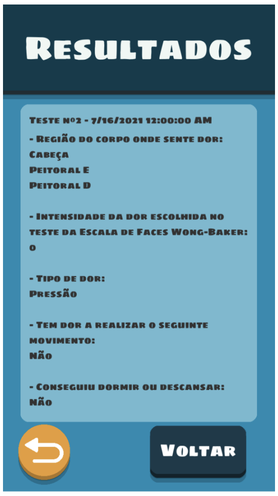

Figure 4.19: Demonstration of the result of a medical evaluation.

4.2 Back-end Implementation

All the information obtained and created when using the Mobile Augmented Reality (MAR) application must be saved, because there is a need to share and access it in different modules, and at different times. However, the stored data can have different sizes. The larger data is saved in Placenote the server, for the application to run as smooth as possible, while the smaller data (information needed in different modules of the application) is saved on the device, to be accessed quicker.

4.2.1 Mobile Storage

Unity program has a built-in class called *PlayerPrefs* that can store *strings*, *floaters* and *integers* values, making it easy to persist data between scenes. Since the data is stored between sessions, it must be saved on the device memory. The exact location where it is stored diversifies depending on the device's operating system, but it is usually somewhere that can be accessed, making it unsecured. The class *PlayerPrefs* is mainly used for efficiently storing data that needs to be constant access and can be changed by the user in the application. It is accessed like a hashtable or dictionary. In future development, only necessary data should be saved using the class *PlayerPrefs*, and it should be encrypted to preserve their security. The rest should be stored in a server, where can only be accessed by the developers.

To be ergonomic, data that is access together should be stored on a structure. Accessing it becomes easier e direct. For such, the structures must be serializable to be transformed on a JavaScript Object Notation (JSON) *string* [39]. JSON is a lightweight data-interchange format. It is easy for humans to read and write. This format is a popular method of storing data in key-value arrangements to be parsed quickly. To conclude, if the data is an *integer*, *float* or *string* (standard or JSON type), it can be saved using *PlayerPrefs*.

All the information created and updated in the Medical Evaluation module (see summary in Table

4.2) and the Sign-up Patient module (see summary in Table 4.3) are stored using *PlayerPrefs*.

Table 4.2: Data stored in *PlayerPrefs* in the Medical Evaluation module.

Type	Key	Description
Int	PaintNumberTest	Evaluation id.
Int	TestPain	Works like a boolean. When it is 1, the intensity pain test is done; if it is 0, the user has not done the test yet.
Int	LocalizePain	Works like a boolean. When it is 1, the locatise body parts task is done; if it is 0, the user has not done the
String	PaintType	Type of pain that better matches user's pain.
String	SleepWell	Works like a boolean. Either the user slept well (*Sim*) or not (*Não*).
String	MovementPainDescription	Description of what movements cause pain.
String (JSON)	BodyParts	List of string, each one with the name of the body part the user feels pain.
String (JSON)	TestList	List of all evaluations done.
Float	PainLevel	Value of the pain intensity felt by the user.

Table 4.3: Data stored in *PlayerPrefs* in the Sign-up Patient module.

Type	Key	Description
Int	PatientNumberTest	Number of evaluation done by the patient.
Int	PatientAge	Patient's age.
String	PatientName	Patient's first and last name.
String	PatientClinicalPicture	Description of patient's clinical picture.
String	PatientCares	Description of what cares to be taken.
String	DoctorName	Name of the responsible healthcare professional.
String	DoctorEmail	Email of the responsible healthcare professional.
String	Model	What type of model is the patient in (model A or B).

The *BodyParts* JSON *string* is created from a structure of a *strings* array with all the body parts that the user selected in his last evaluation.

The *TestsList* JSON file is created from an array of structures *Test*. The *Test* structure contains the results of the evaluation:

- *int* testID.
- *float* painValue.
- *string* date.
- *string* painType.
- *string* sleepWell.
- *string* movementPain.
- *string*[] bodyparts.

4.2.2 Placenote Server

A key feature of the Placenote SDK was the ability to store data into their servers. Unfortunately, only data in the format of metadata can be stored. However, for the first version of the *inovAR* application, the data that has a significant size corresponds to the maps information generated in the Enjoyment module. To save it, Placenote SDK has a functionality that converts the map data into a metadata file (see Table 4.4) and sends it to their serves, and another functionality that does the opposite. The information stored contains all mapping features data and any information related to digital objects that have been placed.

Table 4.4: Structure for setting map metadata.

Type	Key	Description
string	Name	The map name.
MapLocation	Location	The map location information.
JToken	Userdata	Asbitrary user data, in JSON form.

Figure 4.20: Content associated with a map. This is available in the developer portal.

The *Maplocation* is a class from the Placenote library that contains location data from the map. It stores the GPS altitude, latitude and longitude (of type *float*) from the device when the map is saved.

The *JToken* is a JSON string with all the information from the map. This JSON is created from an array of *ObjInfo* structures. This struct contains the position, rotation, scale, model number and note text, as it is shown below:

- *string* modelType.
- *float* px.

- *float* py.
- *float* pz.
- *float* qx.
- *float* qy.
- *float* qz.
- *float* qw.
- *float* sx.
- *float* sy.
- *float* sz.
- *string* note.

The model number is the identification number from the model's list. The order of this list corresponds to the order that each 3D model was added to the project. One of the existing models is a note, and if the user chooses to place one, the text information is stored in the note text variable. This note it is a virtual post-it that allows the user to choose what information is displayed.

Figure 4.20 shows the metadata file from a map that had only one object model placed in the RW. This metadata has size is relatively small (1.839 **MB!** (**MB!**)), but a metadata file with two more models included has a cost of 10.502 **MB!**, which is an increase of ten times more. We can conclude that storing map's information on the device memory would have a significant cost in performance terms.

5

Results and Evaluation

Contents

This chapter reports the evaluation of the *inovAR* application. Unfortunately, the *inovAR* application could not be published in the *Apple Store*in time to be considered for the dissertation, due to the requiring to follow a long and not always very easy procedure - the approval process could not be finished in time. To circumvent this limitation, the other option to allow healthcare professionals and children to test the proposed Mobile Augmented Reality (MAR) application would be to install it directly from the machine used for development into their devices, or by letting them use our test device. Again, these options were not possible due to the pandemic restrictions. As a final and viable option, a set of videos and a collection of images were prepared to let the potential users have the notion of how it would be like to interact with the various functionalities supported by the proposed MAR application. This was the option that allowed to inquire healthcare professionals and children, asking them to assess the suitability of the adopted methodology and the interface of the *inovAR* application.

5.1 Methodology Validation

To evaluate *inovAR*'s methodology a survey questionnaire was prepared, drawing the essential questions to verify if each module was structured and implemented correctly, as well as to identify its limitations. The goal of these questions is to collect and analyse the healthcare professional opinions, since they were already involved in specifying the requirements leading to the design adopted for the application architecture (as discussed in Section 3.2.1). Also the collection of feedback from children was essential, as they are the potential users to whom the application development was focused.

The questions selected for the validation questionnaire were based on a catalogue of open questions [40], and the feedback was collected by asking users to choose a value between 1 (strongly disagree) and 5 (strongly agree):

- Q1: Do you find this component useful? - *Considera esta componente útil?*;
- Q2: Do you find this component incomplete? - *Considera esta componente incompleta?*;
- Q3: Do you find this component overcomplicated? - *Considera esta componente demasiado complexa?*;
- Q4: Do you find this interface suitable? - *Considera a interface adequada?*;
- Q5: Do you find this interface intuitive? - *Considera a interface intuitiva?*;
- Q6: Do you consider that without the initial explanation you would be able to use this component? - *Considera que sem a explicação inicial seria capaz de utilizar esta componente?*.

Since users could not experience in first hand the *inovAR* application, the questionnaire included video information, which can be accessed online [41], demonstrating the various functionalities of each module. Also, to help each person that answered the questionnaire to have as much information as possible, a description of each module (functionalities and goal) was included, as well as images of the corresponding interfaces (as already shown in Chapter 4).

To analyze the responses and verify whether the subject approves the module in question, we calculate the total percentage validation (Percentage Validation (PV)). This PV is the average of all question PV, and each question PV is calculated the following manner:

- If the question is made with a positive tone (Q1, Q4, Q5 and Q6), the value 5 corresponds to 100% validation. So the PV, in this case, is equal to:

$$PV_{\text{positive}} = (x * 100)/5. \tag{5.1}$$

- If the question is made with a negative tone (Q2 and Q3), the value 1 corresponds to 100% validation. So the PV, in this case, is:

$$PV_{\text{negative}} = ((6 - x) * 100)/5. \tag{5.2}$$

This validation method gives us an idea of how people see the *inovAR* application and if there are issues that need to be more urgent attention. To interpret the PV values obtained, we use Table 5.1.

Table 5.1: Verbal interpretation of the PV values

PV Range (%)	Verbal Interpretation
0% - 10%	Strongly Disagree
10% - 20%	Highly Disagree
20% - 30%	Disagree
30% - 40%	Moderatly Disagree
40% -50%	Slightly Disagree
50% - 60%	Slightly Agree
60% - 70%	Moderatly Agree
70% - 80%	Agree
80% - 90%	Highly Agree
90% - 100%	Strongly Agree

5.1.1 Analysis of Healthcare Professionals' Input

A total of 20 healthcare professionals answered the validation questionnaire. This subsection analyzes the collected results.

5.1.1.A Medical Evaluation Module

As explained in the previous chapters, the Medical Evaluation module contains the (i) Self-Assessment and the (ii) Clinical Information Summary components.

(i) Self-assessment Component

The total PV, computed from the healthcare professional answers corresponding to the self-assessment component of the medical evaluation module, is 90%, obtained from the partial values included in Table 5.2. By examining the PV from each question, it is possible to see that the lowest PV corresponds to the last question, which means that this component, at first view, has some complexity.

The questionnaire also included a text box to provide improvement suggestions, and healthcare professionals suggested to implement either pop-up messages or a brief description (as in the Enjoyment module) of each self-assessment step. Another suggestion was that an evaluation of the pain intensity should be possible for each body part selected as causing pain, since pain can have different intensity values and different types in different body regions. Nevertheless, looking at question 1 PV, we can conclude that one of the proposed solutions (developing a self-assessment test to complement the daily clinical assessment), one of the pillars of this module and the *inovAR* application, is strongly validated.

Table 5.2: Results relative to the Self-assessment component from the healthcare professional's answers.

Question	Average value	PV (%)
Q1	4.90	98.00%
Q2	1.65	87.00%
Q3	1.55	89.00%
Q4	4.60	92.00%
Q5	4.50	90.00%
Q6	4.20	84.00%

To conclude, healthcare professionals strongly agree with the functionalities, structure and interface of this component.

(ii) Clinical Information Summary Component

The total PV for this component, obtained from the partial values included in Table 5.3, is 93.00%. These values show that this component is a key feature of the application.

Table 5.3: Results relative to the Clinical Information Summary component from the healthcare professional's answers.

Question	Average value	PV (%)
Q1	4.80	96.00%
Q2	1.60	88.00%
Q3	1.30	94.00%
Q4	4.65	93.00%
Q5	4.80	96.00%
Q6	4.55	91.00%

To conclude, healthcare professionals strongly agree with the functionalities, structure and interface of this component.

5.1.1.B Enjoyment Module

The total PV, obtained from the partial values presented in Table 5.4 from this module, is 87.83%. Question 3 indicates that this module is not as simple as the module before. The reason is that AR continues to be seen as a complex technology, as 15% of the respondents think that this module is overcomplicated. Nevertheless, we believe that including of AR applications in medicine will help to demystify this idea.

To conclude, healthcare professionals highly agree with the functionalities, structure and interface of this module.

Table 5.4: Results relative to the Enjoyment module from the healthcare professional's answers.

Question	Average value	PV (%)
Q1	4.74	95.00%
Q2	1.55	89.00%
Q3	2.20	76.00%
Q4	4.50	90.00%
Q5	4.55	91.00%
Q6	4.30	86.00%

5.1.1.C Patient Registration Module

The total PV for this module, obtained from the values presented in Table 5.5, is 91.50%. Question 1 has a PV value of 100% as this module is an essential component of the application. The lowest value present in Table 5.5 (81%) does not mean that this module seems complicated to handle the first few times, yet it is something to consider in a future update.

Table 5.5: Results relative to the Patient Registration module from the healthcare professional's answers.

Question	Average value	PV (%)
Q1	5.00	100%
Q2	1.65	87.00%
Q3	1.30	94.00%
Q4	4.55	91.00%
Q5	4.80	96.00%
Q6	4.05	81.00%

To conclude, healthcare professionals strongly agree with the functionalities, structure and interface of this module.

5.1.1.D Results Module

The total PV for this module, obtained from the values listed in Table 5.6, is 84.83%. One of the healthcare professionals suggests that instead of identifying each evaluation as "test" - *teste* -, the term "self-assessment" - *auto-avaliação* should be used instead - see Fig. 4.18. This suggestion should be followed in the next update since we should always be precise and use the correct terminology.

Table 5.6: Results relative to the Results module from the healthcare professional's answers.

Question	Average value	PV (%)
Q1	4.80	95.79%
Q2	2.00	80.00%
Q3	1.95	81.00%
Q4	4.35	87.00%
Q5	4.30	86.00%
Q6	3.95	79.00%

To conclude, healthcare professionals highly agree with the functionalities, structure and interface of this module.

5.1.2 Analysis of Users' Input

A total of 19 users answered this questionnaire. This subsection will analyze the result from the answered questions. This group is composed of children between 6 and 12 years of age (26.3%) and from 13 to 17 years of age (15.8%), and others (57.9%). The inclusion of other people, older siblings, parents, or simply people over 18 years old was because we wanted to receive their feedback to understand if this application could expand in the future to older ages. This group will only evaluate the two modules that are available for the user's use (Medical Evaluation and Enjoyment modules).

5.1.2.A Medical Evaluation Module

(i) Self-assessment component

The total PV from the children, obtain by the values of table 5.7 from this module, is 93.33%. Where the total PV from the children, obtain by the values of table 5.8 from this module, is 92.73%. By comparing both table 5.7 and 5.8, we can verify that people over 18 years old feel that the questions from the self-assessment may be insufficient, which is a valid point since the self-assessment was designed for hospitalized children. The results from the last question correspond to feedback previously given by health professionals.

Table 5.7: Results relative to the Self-assessment component from the children.

Question	Average value	PV (%)
Q1	4.88	97.50%
Q2	1.25	95.00%
Q3	1.50	90.00%
Q4	4.75	95.00%
Q5	4.88	97.50%
Q6	4.25	85.00%

Table 5.8: Results relative to the Self-assessment component from the other users.

Question	Average value	PV (%)
Q1	5.00	100%
Q2	1.91	81.82%
Q3	1.18	96.36%
Q4	4.73	94.55%
Q5	4.91	98.18%
Q6	4.27	85.45%

To conclude, the users strongly agree with the functionalities, structure and interface of this component.

(ii) Clinical Information Summary component

The total PV from the children, obtain by the values of table 5.7 from this module, is 90.42%. Where the total PV from the children, obtain by the values of table 5.8 from this module, is 94.55%. Question 6 PV has a value lower than expected from the children answers because two children, from 13 to 17 years of age, answered that they would not be able to use this component. Since this component is merely a display of information written by a healthcare professional, we have to disregard their answers (without their responses, the PV from question 6 would be 96.67%), even because they both answer ”1” in the question 2 (if the component was overcomplicated).

A user (over 17 years old) suggested implementing a feature that allows the user access to his prescriptions. This suggestion for the current target people (children) may not be a key feature. However, in the future, if the age of the target user increases and if the application expands to home patients, it would be a feature to consider. Another suggestion was to display also the date when the patient was hospitalized.

Table 5.9: Results relative to the Clinical Information Summary component from the children.

Question	Average value	PV (%)
Q1	4.75	95.00%
Q2	1.50	90.00%
Q3	1.50	90.00%
Q4	4.63	92.50%
Q5	4.88	97.50%
Q6	3.88	77.50%

Table 5.10: Results relative to the Clinical Information Summary component from the other users.

Question	Average value	PV (%)
Q1	4.91	98.18%
Q2	1.73	85.45%
Q3	1.09	98.18%
Q4	4.73	94.55%
Q5	4.91	98.18%
Q6	4.64	92.73%

To conclude, the users strongly agree with the functionalities, structure and interface of this component.

5.1.2.B Enjoyment Module

The total PV from the children, obtain by the values of table 5.7 from this module, is 92.08%. Where the total PV from the children, obtain by the values of table 5.8 from this module, is 83.64%. If AR for healthcare professionals and people over 17 years old is a complex technology, children are expected to consider it even more.

If this module could be related to topics of interest such as civic responsibility, social and environmental sustainability or healthy living, among others, it was a suggestion from a user over 17 years old. This new feature and the initial features (subsection 3.2.3.B, components 2,3 and 4) that were not implemented would significantly upgrade. Then, this module would continue to allow users to be entertained and then have the tools to learn about important matters (i.e. be able to learn how to be a better person than he was the day before).

To conclude, the users strongly agree with the functionalities, structure and interface of this component.

Table 5.11: Results relative to the Enjoyment module from the children.

Question	Average value	PV (%)
Q1	4.75	95.00%
Q2	1.13	97.50%
Q3	1.38	92.50%
Q4	4.75	95.00%
Q5	4.75	95.00%
Q6	3.88	77.50%

Table 5.12: Results relative to the Enjoyment module from the other users.

Question	Average value	PV (%)
Q1	4.45	89.09%
Q2	2.00	80.00%
Q3	1.45	90.91%
Q4	4.27	85.45%
Q5	4.27	85.45%
Q6	4.18	83.64%

5.2 System Usability Scale

In other to evaluate the final application, we developed a ten-question questionnaire similar to a System Usability Scale (SUS). The SUS [42] is the most frequently used questionnaire to measure usability. Joh Brook created it in 1986. It has become an industry standard, with references in over 1200 articles and publications. The benefits of using it are:

- It is a straightforward scale to administer to participants.
- Can be used on small sample sizes with reliable results.
- It can effectively differentiate between usable and unusable systems.

System Usability Scale (SUS) is composed of 10 questions scored on a 5 point Likert scale of the strength of agreement. The Likert scale can be a five-point or seven-point scale, which allows the participant to express how much he agree or disagree with a particular statement. Its final score can range from 0 to 100, where the higher score is the higher usability the system have. Since the questions alternate between having a positive and negative tone, calculating the total score can be complex. The total score of SUS is calculated through the formula defined by Brooke:

- For each of the odd-numbered questions (positive tone), subtract one from the user response.

$$Odd_{\text{SUS}} = (x - 1). \tag{5.3}$$

- For each of the even-numbered questions (negative tone), subtract user response from 5.

$$Even_{\text{SUS}} = (5 - x). \tag{5.4}$$

- Add up the new values (range from 0 to 40) and multiply it by 2.5 (range from 0 to 100).

$$SUSscore = (Q1 + Q2 + Q3 + Q4 + Q5 + Q6 + Q7 + Q8 + Q9 + Q10) * 2.5. \tag{5.5}$$

SUS score are not percentages and should be considered only in terms of their percentile (68). A SUS score above 68 would be considered above average, and anything below that is below average. The final score represents the usability performance in the aspects of effectiveness, efficiency and overall ease of use. The mean score for each adjective rating was based on the table 5.13 [43].

Table 5.13: Interpretation of SUS scores.

Adjective	Mean SUS Score	Standard Deviation
Worst Imaginable	12.5	13.1
Awful	20.3	11.3
Poor	35.7	12.6
Okay	50.9	13.8
Good	71.4	11.6
Excellent	85.5	10.4
Best Imaginable	90.9	13.4

We could not use the SUS itself because the inovAR application was not used by enough people. Instead, we adapted the questions to evaluate the participants' feedback from the global view of the inovAR application. However, since the questionnaire was in Portuguese, we modified the Portuguese translations of each question [5] (Table 5.14). Table 5.15 shows the final result.

Table 5.14: Original item vs corresponding item in European Portuguese.

Original Item	Correspondig item in Portuguese
I think that I would like to use this system frequently.	Acho que gostaria de utilizar este produto com frequência.
I found the system unnecessarily complex.	Considerei o produto mais complexo do que necessário.
I thought the system was easy to use.	Achei o produto fácil de utilizar.
I think that I would need the support of a technical person to be able to use this system.	Acho que necessitaria de ajuda de um técnico para conseguir utilizar este produto.
I found the various functions in this system were well integrated.	Considerei que as várias funcionalidades deste produto estavam bem integradas.
I thought there was too much inconsistency in this system.	Achei que este produto tinha muitas inconsistências.
I would imagine that most people would learn to use this system very quickly.	Suponho que a maioria das pessoas aprenderia a utilizar rapidamente este produto.
I found the system very cumbersome to use.	Considerei o produto muito complicado de utilizar.
I felt very confident using the system.	Senti-me muito confiante a utilizar este produto.
I needed to learn a lot of things before I could get going with this system.	Tive que aprender muito antes de conseguir lidar com este produto.

With the responses from all participants to our SUS questionnaire (table 5.16), we were able to calculate the SUS score. So, if we apply the equation 5.5 to all the values from the column Average of SUS score, we obtain a SUS score of 88.43. The SUS scores from the healthcare professionals, children and other users were 87, 86.88 and 91.36, respectively.

This score falls into the Excellent category of usability of the design solution. This SUS score means that to achieve the designated goals with effectiveness, efficiency and satisfaction of *inovAR* application has an Excellent overview from all participants from this questionnaire. By looking at table 5.16, we can observe that the lower SUS value corresponds to question 4. The SUS score from each group of

Table 5.15: Final adaptation from the translated questions.

Question	Final adapting in Portuguese
Q1	Gostaria de utilizar esta aplicação com frequência?
Q2	Considera que a aplicação inovAR seja mais complexa do que necessário?
Q3	Considera que a aplicação inovAR seja fácil de utilizar?
Q4	Considera que necessitaria da ajuda de um técnico para conseguir utilizar esta aplicação?
Q5	Considera que as várias funcionalidades desta aplicação estão bem estruturadas e integradas?
Q6	Considera que esta aplicação tem muitas inconsistências?
Q7	Calcula que a maioria das crianças doentes dos 6 aos 17 anos aprenderiam a utilizar rapidamente esta aplicação?
Q8	Considera que esta aplicação seja muito complicada de utilizar?
Q9	Sentir-se-ia muito confiante ao utilizar esta aplicação?
Q10	Considera que teria que aprender muita informação para conseguir manusear esta aplicação?

participants for question 4 were 1.6, 2.38 and 2.00. Even though, having had a SUS score in the range of Excellence, the SUS value obtained by children in question 4 indicates the need for a minor review and improvement to the design.

Table 5.16: Auxiliary values for determining the SUS score

Question	Average of Likert value	Average of SUS value
Q1	4.44	3.44
Q2	1.40	3.60
Q3	4.66	3.66
Q4	1.99	3.01
Q5	4.53	3.53
Q6	1.29	3.71
Q7	4.86	3.86
Q8	1.36	3.64
Q9	4.27	3.27
Q10	1.34	3.66

The next step must be to publish the first version of *invovAR*, realize another SUS questionnaire and compare the results with these.

5.3 Application Limitations

Before the *inovAR* application is ready to publish a then tested in a real case, it is important to note that AR (and consequently our application) faces a number of challenges that must be overcome for it to thrive. Most of these issues are anticipated to be solved by continuous progress in information technology (IT).

These challenges are related to the hardware from the mobile device and software of the *inovAR* application. The fact that the *inovAR* application is built only for iOS devices, the cost of having enough devices available in hospitals is not as affordable as Android devices. Apple releases a depth-sensing *liDAR* sensor (available on the newest iPhone 12 Pro and iPhone 12 Pro Max and 2020 iPad Pro) that will revolutionize 3D meshing. *LiDAR* scanner is a type of time-of-flight camera. Some other smartphones measure depth with a single light pulse, whereas the devices with this type of *LiDAR* tech sends waves of light pulses out in a spray of infrared dots and can measure each one with its sensor, creating a field of points that map out distances and can mesh the dimensions of an environment and the objects in it. However, this technology only seems available to the standard user in the future (since those devices cost around 1000€).

Consequently, the devices that may be affordable have not the most powerful processors to provide constant or long-duration services of tracking and collecting features points to work accurately. While using the Enjoyment module, we noticed that when we scan large areas and collect features points during long periods, the mobile device will increase its temperature, and then the application will crash. Until the price of the new devices decreases, there must be a particular focus on managing the obtained data.

The Placenote SDK used is already outdated since the new version released and used in the *inovAR* application have technicals errors when combining with the newest version of ARkit, Xcoder and Unity. The versions of ARkit SDK and Unity used were 2.1.1 (newest is 3.1.3) and 2019.2.21 (newest is 2020.1). The inovAR application crashed a few times due to the Placenote SDK, making the user reinitiate the mobile application to return to work normally.

The inovAR application has an implementation bug, noticed later on, that crashes the application. This software error is sometimes caused when the healthcare professional introduces an invalid email in the Patient Registration Module.

6

Conclusion and Future Work

Contents

In this chapter we summarize our results and conclusions, discuss our future work.

6.1 Conclusions

Augmented Reality (AR) technology holds a promising future and an enormous potential for application in medicine. The use of AR in medicine may change the way surgeries are prepared and performed. Medical training and post-surgical treatments can be executed with ease using AR displays.

This thesis describes the implementation process of developing an AR system in the medical field. After analyzing the several sectors in which AR technology can be applied to accomplish this task, we have focused on hospitalized pediatric patients. Our MAR application's primary objective is to develop an ecosystem for the children. Allowing pediatric patients to carry out self-assessment of their health condition and enabling them to explore AR features to end the monotony caused by their hospitalization are the main features in the *inovAR* application.

To accomplish this task, firstly, we draw the prototype idea and then inquired the healthcare professionals' opinion for validation of which features should be implemented in the architecture of our MAR to accomplish the goals established. Secondly, using the Unity program, we builded the *inovAR* application. Thirdly, even though the *inovAR* application was not published and tested in a real case study, we managed to obtain helpful feedback from healthcare professionals, children, and future users (people over 18 years old) through a validation methodology questionnaire and a SUS questionnaire. The results from those questionnaires were excellent, with the SUS score being 88.43. The SUS questions were adapted to the state of the *inovAR* application.

According to the results obtained, we firmly believe that once published, the *inovAR* application will contribute to demystifying the idea that AR technology is overcomplicated and the concerns around it. Our MAR will improve the healthcare professionals-patients relationship and improve the emotional state, and ultimately the patient's health. At the same time, by allowing the patient to express himself in alternatives ways, in a direct connection with the clinical team, facilitating a more pervasive and continuous monitorization of his health status, the daily clinical assessment will be improved, by facilitating a more pervasive and continuous monitorization of his health status, and also allow to administrate therapies subtly, promoting a better acceptance and adherence by the patients.

6.2 Future Work

Throughout the results obtained by our validation and SUS questionnaires, we saw that the MAR application is a promising tool for a change in hospitalized pediatric patients' lives. However, there are improvements to be made that were mention during this thesis. In this section, we discuss the future improvements.

The "back-end" implementation need to be revised. Must be developed an independent database, where all the information will be stored safely, and therefore creating a website to manage it. The website will allow healthcare professionals to control their patients' data. The Results and the Patient Registration modules would be imported to the website, making the *inovAR* application for patient's use only. Healthcare professionals can then check patients' information without using the patients' devices or searching through their emails.

Additionally, implementation issues should be addressed, such as changing the way the Self-assessment component work. The pain intensity test should be tested for each body part the patient feels pain, as suggested by a healthcare professional.

As mentioned in the Application Limitations section, the *inovAR* application is using outdated software. Updating the software used is crucial if we want to explore the AR features to the fullest.

Features that initially thought that were not implemented in the Enjoyment module will enrich the *inovAR* application. Inclusion of daily challenges to create a more stimulating experience. This component can be aimed at subjects like civic responsibility or social and environmental sustainability, as a participant of the SUS questionnaire suggested. Notably in addressing long-term hospitalizations, integration of school homework so that children can catch up on their studies. Creation of a schedule to help the patient establish a routine and remind him to take the self-assessment tests.

Finally, maybe the most significant step in improving our ability to reach every patient is building a version of the *inovAR* application for Android devices, since it will be available to almost every device.

For the further future, the application could be extended to all patients ages and for home hospitalization patients. If the input information given by the patient is sufficient for the responsible healthcare professional to monitor his health, it can reduce costs of dislocation and consults. With AR technology growing as it has been, numerous features could be developed. The latest AR SDKs have implemented Machine Learning (ML) to improve recognition and tracking.

Ultimately, Augmented Reality (AR) has a bright future ahead, and we hope this thesis paves the way into it.

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