How Augmented Reality can help surgeons and patients

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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.

***Index Terms*—Augmented Reality; Mobile Augmented Reality; Real World; Self-assessment; System Usability Scale;**

I. 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 [1]. While our environment is 3D, the digital data remains confined to 2D devices and displays. Traditionally, the difference between the virtual and real world was the contrast between identity and body. Thus, AR was born.

Augmented Reality 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.

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.

II. Motivation

Our motivation is to make a difference in patients' lives and helping to improve the patient condition by developing a Mobile Augmented Reality (MAR) application [2] 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 [3].

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 [4].

In this dissertation, we developed a 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 hospitalised 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.

III. Background

With the evolution of time, the technology of AR systems has evolved in such a way that the major surveys papers [5]–[8] 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 Augmented Reality, we can conclude that AR is complementary to immersive Virtual Reality (VR). AR is a variant of 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 VR into the RW, when the surroundings are predominantly real.

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.

IV. Methodology

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 hospitalised 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. Lamentably, hospitals have been overcrowded, and health workers often feel drained and overwhelmed, lacking sleep, overworking hours, and do not 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.

A. 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.

B. Questionnaire Analysis

1) 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 hospitalised child has difficulty providing accurate answers in a medical evaluation, we learn that a child should be over six years old 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 are the questions that constitute the base model:

- Q.1: Region of the body where the patient feels pain or discomfort;
- Q.2: The intensity of pain or discomfort;
- Q.3: The type of pain or discomfort;

- Q.5: If the pain or discomfort is due to movement or position;
- Q.6: If the patient managed to sleep well;

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 [9]. 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.1 - with 80.6% of the healthcare professional choosing it. 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.

Fig. 1. Wong-Baker scale faces.

For Model B, since the children's age is more advanced, the pain assessment instrument chosen was Numerical Rating Scale (NRS) - illustrated in Fig.2, with 88.9% of people voting for it. The NRS is a segmented numeric version of the 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").

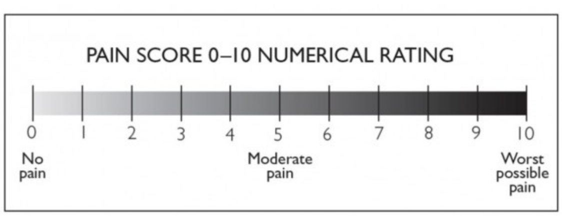

Fig. 2. Illustration of the numerical rating scale.

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.

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 hospitalisation (with a 75% agreement) in a language suitable for the patient. Model A should use a simpler language, while Model B can be more detailed.

2) Enjoyment Module: The responses collected (86.1%) agreed that sick children suffer from stress during hospitalisation 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 hospitalised (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 hospitalisations, 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%).

V. Implemented Mobile AR Application

This section presents the architecture of the MAR application implemented and details the implementation of the mobile AR application developed in this dissertation, entitled *inovAR.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. 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.

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

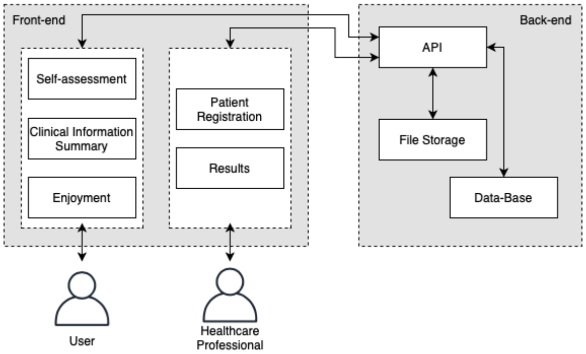

Fig. 3. Architecture of the proposed mobile AR application.

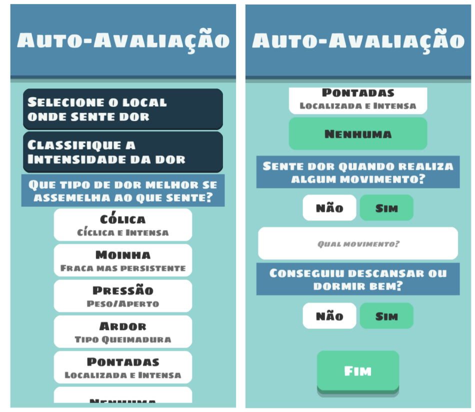

Fig. 4. Self-assessment Evaluation interface.

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.

A. Medical Evaluation Module

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

(i) Self-Assessment:

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. 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.

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 were divided according to [10] [11].

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 and the Numerical rating scale 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. 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.

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). 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 (V-D Mobile Storage).

(ii) Clinical Information Summary:

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 hospitalisation.

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 hospitalisation 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.

B. Enjoyment Module

In the Enjoyment module, the only feature presently implemented concerns the ability to virtually redecorate the space

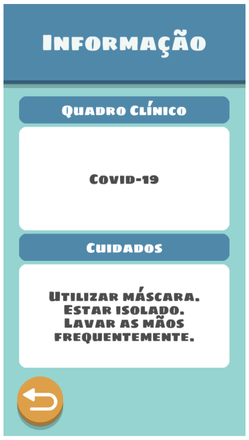

Fig. 5. Clinical Information Summary interface.

in which the child is hospitalised. The user starts with two options: (i) to create a new map; or (ii) to load and modify a previously created map. 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. 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.

The implementation of the Enjoyment module was the most challenging one. It is in this module that AR technology was implemented. 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 Software Development Kits (SDK), we end up using Placenote SDK [12] 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.
- 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.6). In this module, a notification panel (at the top of the device) helps the user in each task because of its complexity.

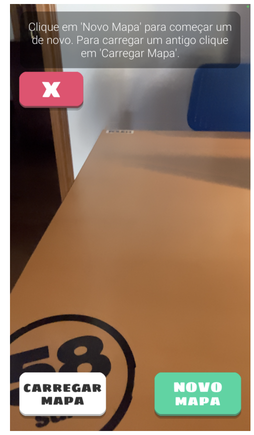

Fig. 6. Opening scene from Enjoyment module.

(i) Creation of a New Map:

If the user selects the option to create a new map, a new AR 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.

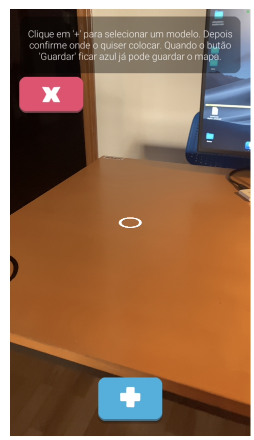

Fig. 7. Display of the white reticle after SDK recognised a plane.

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 (shown in Fig. 7). After choosing the model, the user can change his scale, orientation and rotation using the top buttons (shown in Fig.(a) 8). 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 [13]. When the button *Guardar* (save map) is filled (starts grey and ends blue), the map can be saved (see Fig.(b) 8). 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.

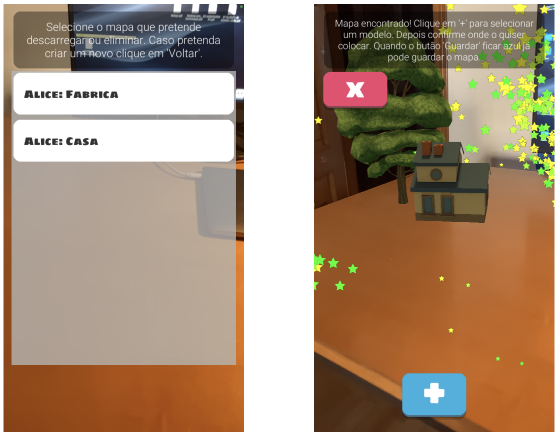

Fig. 8. (a) 3D model selected in process of been placed. (b) Map with enough features points collected to be saved.

(ii) Loading a Previous Map:

The load map functionality loads a list of all maps associated with the patient, as illustrated in Fig.(a) 9. 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. 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.(b) 9 match those shown in Fig. **??**.

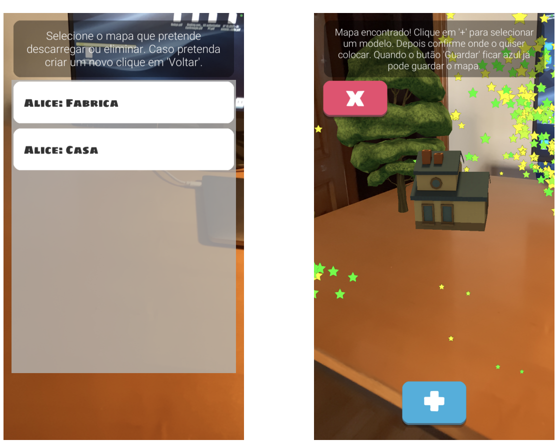

Fig. 9. (a) Display of all maps found.(b) Map loaded and found.

C. 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. 10. 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 @ 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.

Fig. 10. 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.

D. 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. 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.

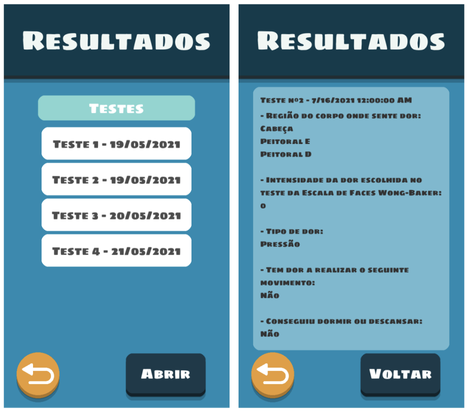

Fig. 11. Results module interface.

VI. Back-end Implementation

All the information obtained and created when using the 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 (i) 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 (ii) the device, to be accessed quicker.

(i) 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 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.

By comparing the sizes from metadata file with only one object placed on the map (1.839 MB) with a metadata file with three models (10.502 MB), we can verify an increase of ten times more. This increase is due to the fact that during the AR session the mobile device continuously capture features points. We can conclude that storing map's information on the device memory would have a significant cost in performance terms.

(ii) 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. All the information created and updated in the Medical Evaluation module and the Sign-up Patient module are stored using *PlayerPrefs*.

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.

VII. Results and Evaluation

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. 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.

A. 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 analyze 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 V). 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 [14], 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?*.

To analyze the responses and verify whether the subject approves the module in question, we calculate the total 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:

$$PV_{\text{positive}} = (x * 100)/5. \tag{1}$$

- 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:

$$PV_{\text{negative}} = ((6 - x) * 100)/5. \tag{2}$$

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.

B. Analysis of Healthcare Professionals' Input

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

1) 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%. By examining the PV from each question, it is possible to see that the lowest PV (84%) corresponds to the last question, which means that this component, at first view, has some complexity.

(ii) Clinical Information Summary Component:

The total PV for this component is 93.00%. These values show that this component is a key feature of the application.

2) Enjoyment Module: The total PV is 87.83%. The PV value from question 3 (76%) 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.

3) Patient Registration Module: The total PV for this module is 91.50%. Question 1 has a PV value of 100% as this module is an essential component of the application. The lowest PV's values corresponds to question 6 (81%). This value does not mean that this module seems complicated to handle the first few times, yet it is something to consider in a future update.

4) Results Module: The total PV for this module 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. 11. This suggestion should be followed in the next update since we should always be precise and use the correct terminology.

C. 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).

1) Medical Evaluation Module: (i) Self-assessment component:

The total PV from the children is 93.33%. Where the total PV from the children is 92.73%. Analyzing the PV's values, 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 (as PV value from question 2 is 81.82%). The results from the last question correspond to feedback previously given by health professionals.

(ii) Clinical Information Summary component: The total PV from the children is 90.42%. Where the total PV from the children 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.

2) Enjoyment Module: The total PV from the children is 92.08%. Where the total PV from the children 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 IV-B2, 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).

D. System Usability Scale

In other to evaluate the final application, we developed a ten-question questionnaire similar to a System Usability Scale

(SUS). SUS [15] 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.

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:

- Add up the total score for all odd-numbered questions, then subtract 5 from the total to get (X).
- Add up the total score for all even-numbered questions, then subtract that total from 25 to get (Y).
- Add up the total score of the new values (X+Y) and multiply by 2.5.

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 [16].

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 based our translations on [17].

With the responses from all participants to our SUS questionnaire, we obtain a score of 88.43. 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.

VIII. 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.

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 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.

IX. Conclusions

Augmented Reality 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.

X. 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 and creation of a schedule to help the patient establish a routine to remind him of self-assessment tests. 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 to improve recognition and tracking.

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

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