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Virtual Reality System Controlled by Embedded Artificial Intelligence for Supporting Phobia Treatment

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Abstract In recent years, the health area has received technological contributions that provide support for diagnostic practices, monitoring, and treatment of different disorders and diseases, mainly combining various techniques of Artificial Intelligence, Virtual Reality, and Mobile Computing. There are many challenges to integrating these technologies and providing solutions that consider the automation of processes, the simplification of interaction between professionals and patients, the low price of equipment, the individualization of use, mobility, and the use of Artificial Intelligence strategies. Aiming to overcome the limitations of two previous works, which applied technological combinations in the desensitization of stress and phobias, this work aims to develop a technological combination that integrates an autonomous and low-cost virtual environment, with multi-agent control and natural language communication support, to be used in the Treatment by Exposure in Virtual Environments - VRET in the area of Clinical Psychology, more specifically related to Anxiety Disorders. Low-cost virtual reality glasses were used, with visualization on a smartphone. The prototype, called PhobIA 3DS, is controlled by multi-agents that have modules for capturing physiological signals (heart rate); uses natural language to obtain the level of anxiety perceived by the patient; considers these two pieces of information in a Fuzzy system, which, in turn, generates a response on the calculated level of anxiety; and controls and changes the display of specific scenarios for each level of anxiety. Finally, the system was evaluated by a group of 6 experienced psychologists to verify aspects of the interface, relevance, and usability. The data obtained by the evaluation showed positive results and good prospects for using the system in real activities. As a contribution, this work created an integration of AI technologies in an ESP32 microcontroller connected to a smartphone and attached to low-cost goggles. This combination of technics opens perspectives for adopting affordable technologies in phobia treatments.

Keywords: Multi-agent, Fuzzy Logic, Virtual therapy, 3-D virtual environment, Phobia.

1 Introduction

In recent years, the health domains have received technological contributions that have altered the practices of diagnosing, monitoring, and treating various disorders and diseases [Nandakumar *et al.*, 2009], [Molitor, 2012], [Tian *et al.*, 2019]. Current techniques in data visualization and analysis, communication, and tridimensional (3-D) imaging, combined with Artificial Intelligence (AI) technologies [Tian *et al.*, 2019], mobile computing [Stutzel *et al.*, 2019], Internet of Things (IoT) [Kaur *et al.*, 2019], and Virtual Reality (VR) [Kosonogov *et al.*, 2023] have driven the creation of systems and applications that are increasingly sophisticated, comfortable, and accurate.

However, each technology presents weaknesses related to specificities related to the application domain. In the health sector, many challenges are associated with using new technologies and they relate to the accuracy of systems, development and use costs, telecommunications, lack of knowledge from the healthcare team, and difficulty in accessing appropriate equipment, among others [Abreu *et al.*, 2011; Nascimento Neto *et al.*, 2020; Novaes and Soárez, 2020; Thakare *et al.*, 2022; Ilin *et al.*, 2022].

Specifically, the field of treating neuropsychiatric disorders has explored various technologies to reproduce virtual scenarios for cognitive stimulation, panic syndrome treatments, and various syndromes. In Riva [2005], virtual reality is considered as effective as reality in inducing emotional responses. Nugraha [2021] presents a review of the literature on the use of Virtual Reality Exposure Therapy (VRET) in patients with Post-Traumatic Stress Disorder (PTSD) and concludes that VRET allows for more controlled and realistic stimuli. According to Pereira *et al.* [2020], exposure therapy using virtual reality is a relevant tool for treating phobias, which can be an option if using more limited immersion equipment, such as smartphones inserted into low-cost support. VRET allows patients to receive different levels of stimuli using traumatic scenes, exploring visual, auditory, and tactile feedback immersion, corresponding to the principle of systematic desensitization (SD).

For Kothgassner *et al.* [2022], VR-based biofeedback is increasingly widespread in anxiety disorder treatment. Biofeedback is a method that uses biosensors, such as electrodes, to measure the patient's physiological reactions in real-time. This physiological response is not a conscious process, and in general, it can be identified using different measures, such as skin electrodermal activity and heart rate.

Nevertheless, the use of technologies in this field does not only have positive aspects. In this sense, Botella *et al.* [2004] highlighted some disadvantages of VRET: the cost of software and specific equipment, the difficulties therapists face in handling this equipment, and the lack of flexibility to individualize programs according to each individual's needs. Almost 20 years have passed, and research has advanced, but these barriers persist, regardless of the technological combinations adopted.

For individualizing the user experience into virtual scenes, it is fundamental to have controls with some level of intelligence. Considering these problems, Oliveira *et al.* [2012], developed a system to desensitize people with PTSD, which was composed of two modules. The first module controlled a Fuzzy system, which received two types of data provided by the therapist: the patient anxiety level, based on a psychometric scale (SUDS - Subjective Units of Disturbance Scale), and their heart rate. The Fuzzy system combined these two variables and generated the calculated anxiety level. In turn, the doctor received this information from the Fuzzy system and passed it on to the ARVET, which was responsible for presenting the Virtual Reality (VR) scenes. In this case, the adopted Artificial Intelligence (AI) technique was limited to a Fuzzy module in which the therapist is responsible for providing the system with the level of anxiety mentioned by the patient. The scenes were presented on a flat screen, and the patient uses glasses similar those from 3-D movies. This system had the disadvantages of needing a specific physical environment for the system's use and the constant intervention of the therapist in capturing the heart rate, inputting this data into the system, and managing the presentation of scenes.

A second work, by Cons *et al.* [2021], aimed to overcome some of the problems of the previous system, developing an environment called EMVR, which integrated AI and VR techniques using EMDR (Eye Movement Desensitization and Reprocessing) strategies to desensitize past traumatic events. The system is a 3-D representation of a clinic with a virtual therapist who induces the user to perform eye movements while communicating with them through speech. This work evolved the proposal by Oliveira *et al.* [2012], using a smartphone in low-cost support, facilitating access to the 3-D scenes, and also adopted a Fuzzy module to calculate the patient's anxiety level. Based on the result of the Fuzzy module, the VR module increased or decreased the speed of the ball guiding the eye movement. This system was modeled using the Multi-agent approach, but its implementation did not include automated system control. The therapist had to provide the system with the SUDS scale value and the patient's heart rate.

1.1 Motivation

The works of Cons *et al.* [2021] and Oliveira *et al.* [2012] highlighted the technical difficulties in developing automated systems that integrate AI modules with other technologies. They stressed the difficulty professionals had in handling the systems and equipment involved in the user experience and the necessity of expertise in setting up visualization apparatus and getting heart rate manually to pass the information to the system.

The limitations of these works encouraged the search for new solutions that consider process automation, simplifying the interaction between professionals and patients, low cost, individualization in use, mobility, and the use of Artificial Intelligence strategies. In this context, the possibility arises to group various technologies into a powerful small-sized device: an embedded system on a board that incorporates software and hardware to support a system. A device for embedded systems can integrate software and hardware into a single piece of equipment with microcontrollers, sensors, and actuators, which do not require external components. Generally, they are designed for specific applications and do not support other applications or the connection of new peripherals [Ebert and Salecker, 2009].

1.2 Objectives

Aiming to minimize the previously mentioned disadvantages of VRET and considering the results of the conducted literature review, this work aims to present a technological combination that integrates an autonomous and low-cost virtual environment, with multi-agent control and natural language communication support, to be used in the Treatment by Exposure in Virtual Environments - VRET in the area of Clinical Psychology and the application area will be related to Anxiety Disorders, specifically phobias.

There are some physiological and behavioral symptoms associated with phobia. It can generate physical symptoms such as increased heart rate and sweating, affect thoughts generating frightening thoughts, and behavioral symptoms like avoiding situations [Chrousos, 2009].

For the prototype construction, some software and hardware technologies were adopted. Low-cost virtual reality goggles were used for visualization support, with scenes displayed on a smartphone. The PhobIA 3DS prototype is controlled by multi-agents and integrates modules for capturing physiological signals (heart rate) by a low-cost sensor. Phobia 3DS explores natural language processing (NLP) to obtain the anxiety level perceived by the patient and joins these two pieces of information in an embedded Fuzzy Logic module, which generates a response about the calculated anxiety level. An agent module controls and alters the display of specific scenarios for each calculated anxiety level. The scenarios presented to the users can be altered in real-time with minimal interference from the therapist and considering the needs of each patient. All of these procedures are processed in parallel.

1.3 Methodology

Figure 1 presents the steps of the adopted methodology. First, the basic concepts were studied. Then, related works and associated technologies were discussed. The system requirements were defined based on the results of these studies. A prototype was developed considering some technological combinations. A preliminary evaluation was carried out with mental health professionals.

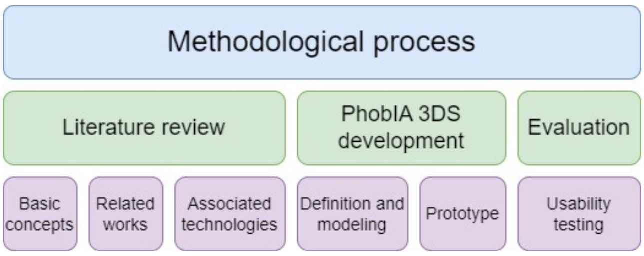

Figure 1. Steps considered in PhobIA 3DS development.

The system is based on two input variables and one output variable. The input variables used in the system are the anxiety reported by the patient and their heart rate measured by a sensor, while the output variable is the calculated anxiety. The level of anxiety reported by the patient uses the SUDS (Subjective Units of Distress Scale) [Wolpe, 1990], which is characterized by a scale, typically from 0 to 10, where zero represents the absence of distress or anxiety and ten defines the maximum level. According to Wolpe [1990], the SUDS scale represents a simple and quick way to promote self-assessment by a patient when exposed to potential discomfort situations in therapeutic sessions. This methodology also allows evaluating the effectiveness of the treatment as it is used at different stages of the process [Milosevic and McCabe, 2015]. Table 1 presents the various levels of the SUDS scale [Salkevicius *et al*., 2019]:

Table 1. SUDS scale.

Measurement	Evaluation
Greatest anxiety/distress ever felt	10
Extremely anxious/distressed	9
Very anxious/distressed; cannot concentrate	8
Very anxious/distressed; interference with functioning	7
Moderate to strong anxiety or distress	6
Moderate anxiety or distress, but can continue to function	5
Mild to moderate anxiety or distress	4
Mild anxiety or distress; no interference with functioning	3
Minimal anxiety or distress	2
Alert and awake	1
Completely relaxed	0

2 Related works

This section presents works that consider combinations of technologies addressed in this proposal. After identifying potential technologies that could be used in this work, we defined a research question: What technologies and equipment are adopted in assistive systems?

From this question, keywords and their combinations were defined for use in bibliographic searches. The following search string were applied in both English and Portuguese: (“assistive technology” OR “physiological sensors” OR “Fuzzy logic” OR “microcontroller” OR “embedded systems” OR “natural language” OR “multi-agents” AND “Virtual Reality” AND “anxiety” OR “post-traumatic stress disorder”). These combinations were consulted in the IEEE Xplore, Scopus, and ACM databases. We also considered a search in Google Scholar. In general, we aimed to always combine a health-related term with one or two terms among physiological sensors, software embedding, and/or AI techniques.

As inclusion criteria, articles from journals, conferences, and book chapters published between 2016 and 2023 in Portuguese or English were considered. Exclusion criteria excluded theses and dissertations.

After reviewing the articles, we selected 7 articles, which are briefly described below.

Salgado *et al*. [2018] present an assistive technology system to improve the quality of life for wheelchair users. The proposed system uses Virtual Reality to simulate the paths traveled by a wheelchair in specific environments. Users control the movement in the virtual environment through a joystick or USB keyboard. Although the system proposed by the authors anticipates navigation based on biometric data, the presented version only uses a joystick aimed at simulating the controls of a real electronic wheelchair. The virtual reality system presented utilizes state-of-the-art glasses combined with biometric sensors such as ECG (electrocardiogram) and EDA (electrodermal activity), commonly known as Galvanic Skin Response.

In the work by Gradl *et al*. [2018], the virtual reality environment aims to demonstrate changes in the participant’s heart rate according to what is shown in the virtual scenario. Physiological response to visual stimuli is captured by an ECG sensor that monitors real-time heart rate related to various presented scenes and projects moving heart images so that users can control anxiety by voluntarily controlling their heart rate.

Gnacek *et al*. [2020] describe a comparative study conducted between two types of sensors for measuring heart rate in a virtual environment. The authors simultaneously used a traditional ECG belt-type sensor and a low-cost PPG (photoplethysmography) sensor, which detects changes in blood volume measured between emitted and received light by an LED through the skin. In Gnacek’s work, virtual reality glasses with integrated sensors were used, with no interaction between the scenarios and the measurements taken.

The work by Muñoz *et al*. [2016] offers a complete set of APIs for data handling and transmission in its distribution package. They proposed an open-source framework for acquiring and integrating physiological signals measured by wearable devices, enabling interaction between a Unity3D game engine and sensor data.

Ergan *et al*. [2019] present a study exploring physiological reactions that some virtual archuma combinação tecnológica que integraitectural environments can cause in participants. It discusses how different environmental characteristics can influence human experience. Like previous articles, Ergan’s work also uses biometric sensors to collect physiological measures such as brain activity, skin conductance, and heart activity. A camera captured facial expressions, EEG sensors monitored brain activity, and a muscle movement sensor tracked movements. At the same time, participants navigated through 3-D scenes, analyzing captured data to determine stress levels induced by the 3-D scenes.

Balbin *et al*. [2017] used facial recognition software that considers facial action units (AU) to track facial movements, monitor heart rate, and skin conductance integrated into an Arduino board to aid professionals in remotely diagnosing

PTSD after experiencing the loss of a loved one. Emotional states were evoked using videos available on YouTube and presented in a notebook.

To desensitize the fear of public speaking, Aljabri *et al.* [2020] developed a system to help people practice presentations or personal interviews with less fear. They used 360° videos with VR technology. During practice, the system analyzes the person's voice and heart rate to detect any emotional and physical symptoms of speech anxiety using heart rate sensors connected to Arduino, machine learning, and speech recognition techniques. The system generates messages of self-confidence for the user when it detects increased stress.

Table 2 presents the comparison of functionalities between the works cited and this work.

2.1 Analysis of the relted Works

The previously listed works explore different technological combinations, including sensors, AI, VR, Arduino, among others. In addition to heart rate sensors, various physiological sensors are used, such as ECG sensors, sensors for detecting skin moisture and electrodermal activity, and those integrated into garments. Virtual Reality is used in all the works, although in some cases, there is no communication between the VR environments and the sensors [Ergan *et al.*, 2019; Gnacek *et al.*, 2020; Balbin *et al.*, 2017].

Despite Machine Learning being popular, only one work utilized it [Aljabri *et al.*, 2020], and no other work mentioned the use of AI techniques such as Fuzzy Logic, Multiagents, or Natural Language.

Therefore, based on the observations made, the answer to the research question that guided the search for related works highlights the various technologies used in the development of assistive systems, with emphasis on physiological and cardiac sensors, and Virtual Reality technology.

In this research, we did not find works combining the latest AI and embedded VR technologies. Perhaps the limitations of Arduino boards and the increasing need for processing power have reduced interest in developing more complex systems using this technology. The latest boards have not yet been widely adopted or extensively tested in healthcare contexts.

3 PhobIA 3DS System development

The PhobIA 3DS system uses a low-cost heart rate sensor of the PPG (photoplethysmography) type, whose technique is based on detecting the variation in blood volume measured between the emitted and received light by an LED (light-emitting diode) through the skin [Allen, 2007]. It is the same technology used in commonly sold finger oximeters. According to Kothgassner *et al.* [2022], using biofeedback devices with VR presents promising results but still requires further controlled studies. Therefore, according to the author, adopting a heart rate sensor opens up prospects for obtaining more consistent results for the phobia treatment process.

The prototype also uses a low-cost VR headset of the mRV type.

The main differentiators of this proposal, compared to similar works found in the literature, are:

- Use of an electronic prototyping platform;
- Use of embedded Fuzzy Logic to determine the patient's anxiety level;
- Implementation of Natural Language Processing using the Google API.

Other important objectives of the work are to offer an easily reproducible solution and the possibility of adaptation to different therapeutic scenarios.

PhobIA 3DS will use low-cost 3-D viewing support, which will receive real-time information from a heart rate sensor connected to the patient. The system will also be able to receive voice commands from the patient. Data transmission between the PhobIA 3DS system agents will be via Bluetooth communication, minimizing the use of wires during sessions.

System requirements were defined from the literature in the field and based on the information from the work of Cons *et al.* [2021].

The survey of the functional and non-functional requirements of PhobIA 3DS took into account the need to overcome the limitations observed in the previous works that served as a starting point, as well as in the related works listed in Table 2.

3.1 Functional Requirements

According to Ávila and Spínola [2007], functional requirements refer directly to software functionalities. They describe all the functions that software must perform. The functional requirements of the proposed system are:

- Display a 3-D virtual environment for the treatment of phobias;
- Receive voice responses from the patient;
- Monitor the patient's heart rate in real-time;
- Calculate the patient's anxiety level;
- Present the patient's anxiety level in real-time to a qualified professional;
- Modify the scenes of the 3-D virtual environment according to the calculated anxiety level.

3.2 Non-Functional Requirements

Non-functional requirements are related to specific conditions or qualities that software must possess [Ávila and Spínola, 2007]. In the case of the proposed system, the non-functional requirements are:

- Perform all information transfers between the system and the actors using Bluetooth technology;
- Be portable;
- Have reduced weight;
- Have reduced cost;
- Be comfortable.

Table 2. Comparison of functionalities between the works cited and this work.

	Salgado (2018)	Gradl (2018)	Gnacek (2020)	Muñoz (2016)	Ergan (2019)	Balbin (2017)	Aljabri (2020)	Oliveira (2012)	Cons (2021)	PhobIA 3DS
Arduino or similar devices	N	N	N	N	N	Y	Y	N	N	Y
Physiological sensors	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Low-cost cardiac sensor (PPG)	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Correlation between sensor data	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Embedded Fuzzy Logic	N	N	N	N	N	N	N	N	N	Y
Low-cost VR glasses (mRV)	N	N	N	Y	Y	N	N	N	Y	Y
Natural Language Processing	N	N	N	N	N	N	Y	N	N	Y
VR interacts with sensors	Y	Y	N	Y	N	N	Y	N	Y	Y
Multi-agent system	N	N	N	N	N	N	N	N	Y	Y
Parallel processing	N	N	N	N	N	N	N	N	N	Y

4 System modeling

Implementing a multi-agent system in this work is highly beneficial as each agent is responsible for one or more tasks in a modular structure. Three agents were defined: the Controller agent, the Environmental agent and the Analyzer agent.

The Controller agent receives the information dictated by the patient regarding their anxiety level (0 to 10), as well as their heart rate captured by the sensor. With this information, the Controller agent performs fuzzy logic calculations and determines the patient's calculated anxiety level.

Since low cost is one of the main requirements of the PhobIA 3DS system, external processing of both physiological signals and Fuzzy Logic was chosen using a microcontroller (ESP32). This decision eliminates the need for expensive smartphones. The PhobIA 3DS system anticipates the use of multiple physiological sensors, which requires more processing control, including the use of multiple processing cores and threads.

Figure 2 presents the characteristic diagram of the stages of a fuzzy system applied to the PhobIA 3DS system:

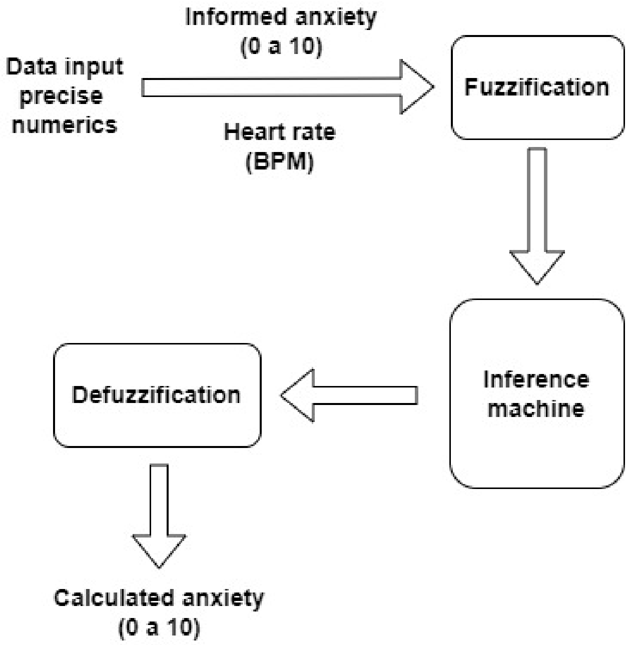

Figure 2. Stages of the Fuzzy module.

The embedded software in Controller agent, written in C++, utilizes the eFLL (Embedded Fuzzy Logic Library) developed by the Robotic Research Group (RRG) at the State University of Piauí (UESPI-Teresina). According to Alves [2012], the eFLL library is a versatile, lightweight, and efficient option for applying Fuzzy Logic in embedded systems and can be used with any microcontroller. The library does not have explicit limitations regarding the number of Fuzzy sets, inference rules, inputs, or outputs [Alves, 2012].

The library uses the MAX-MIN and Mamdani Minimum model [Mamdani, 1977] for inference and composition, and the Center of Area method for defuzzification in the continuous universe.

In the fuzzy module, for each input of user anxiety level combined with the captured heart rate, pertinence functions are created. These functions represent the association between each possible value of the entries and a function that describes the pertinence of that value. The pertinence functions used in the fuzzy calculations were all based on the work of Oliveira *et al*. [2012].

The pertinence functions for the variable "reported anxiety" are automatically generated using three functions: Low, Medium, and High. Each of these functions is defined using trapezoidal or triangular pertinence functions. Similarly, the pertinence functions for the variable "heart rate" are created using the functions Below, Within, Upper Threshold, and Above.

With the pertinence functions defined, fuzzy decision rules are created based on the knowledge of a cognitive-behavioral therapist from the work of Cons *et al*. [2021] which establishes how the output variable should be calculated from the input variables. In the logic of the code, 12 decision rules are defined, which are combined to form a fuzzy controller. This controller will determine the patient's anxiety level according to the input values.

The result of the calculation is a numerical value that represents the anxiety level calculated by the fuzzy module.

Figures 3 and 4 respectively show the pertinence functions for the variable "reported anxiety" and for the variable "heart rate":

Tables 3 and 4 respectively present the equations for input variables and the results of inference rules that generate the system decisions about the anxiety level.

The Environmental agent is responsible for generating and maintaining the entire 3-D environment presented to the pa-

Table 3. Equations of input variables adapted from Cons *et al*. [2021].

Set	Intervals	Pertinences (μ) / Pertinence Lines
	Anxiety	
Low	[0, 3)	μ = 1.0
Low ∩ Moderate	[3 , 5)	Min (μ = -0.5a + 2.5 ; μ = 0.5a – 1.5)
Moderate	5	μ = 1.0
Moderate ∩ High	(5 , 7)	Min (μ = 0.5a - 2.5 ; μ = -0.5a + 3.5)
High	[7 , 10]	μ = 1.0
	Heart rate	
Below	[0 , 60)	μ = 1.0
Below ∩ Within	[60 , 75)	Min (μ = fc/30 – 2 ; μ = -fc/30 + 2.5)
Within	75	μ = 1.0
Within ∩ Upper threshold	(75 , 90)	Min (μ = fc/30 – 2.5 ; μ = -fc/30 + 3)
Upper threshold	90	μ = 1.0
Upper threshold ∩ Above	(90 , 105)	Min (μ = fc/30 – 3 ; μ = -fc/30 + 3.5)
Above	[105, 150]	μ = 1.0

Table 4. Results from Inference Rules application [Cons *et al*., 2021].

	Heart rate			
	Below	**Within**	**Upper Threshold**	**Above**
Reported Anxiety				
Low	Moderate	Low	Moderate	High
Medium	Moderate	Low	Moderate	High
High	High	Moderate	High	High

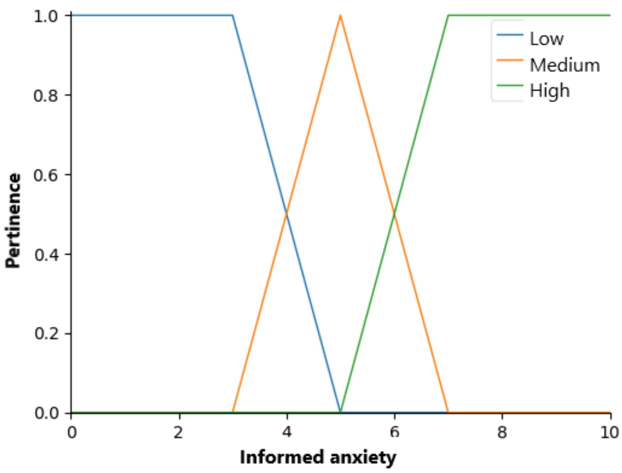

Figure 3. Pertinence functions for the Informed Anxiety variable.

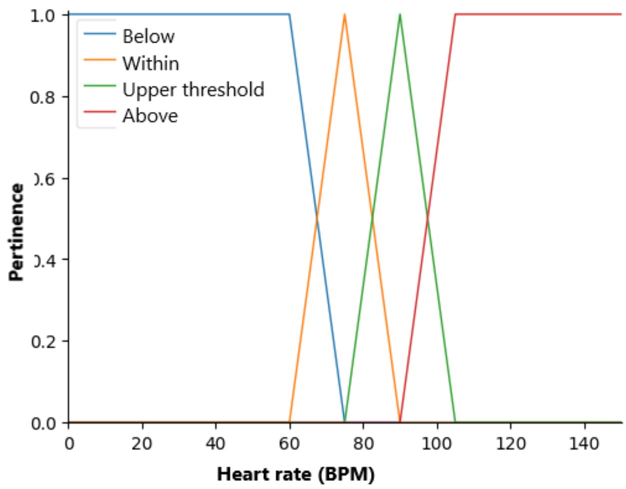

Figure 4. Pertinence functions for the Heart Rate variable.

tient. This agent operates on an Android smartphone attached to the virtual reality goggles. In addition to controlling the 3-D environment, it is also responsible for recognizing the patient's voice information using the Google API. The Environmental agent alters the scenes presented to the patient according to the requests from the controller agent. The Environmental agent is capable of playing 3-D videos stored locally or remotely through predetermined links chosen by the responsible therapist. The order of the environments' execution, as well as the desired phobic stimulus, are configured in a script before the start of each session. A fundamental functionality of the Environmental agent is the screen mirroring capability. Screen mirroring allows the 3-D scenes to be visualized by the patient and the therapist, either on a TV or any screen-compatible device.

The Analyzer agent is on an Android smartphone and is responsible for presenting all session-related information to the therapist in real-time, such as the anxiety reported by the patient, their heart rate, and the anxiety level calculated by the Controller agent. The therapist can also interact with the system using the controls on their smartphone screen. Another feature of this multi-agent system is the ability to add more analyzer agents. This capability is made possible by the Bluetooth BLE module, which supports up to nine simultaneous client connections [Espressif, 2024]. When a new analyzer agent is created, it becomes part of the system and can interact as the initial analyzer agent does. This feature allows multiple professionals to monitor the session simultaneously.

Figures 5 and 6 respectively present the communication and interaction diagram of the system's agents and the software and hardware integration flow. Figure 7 shows the final hardware assembly in the PhobIA 3DS.

5 Execution script

The PhobIA 3DS system, previously configured for a standard execution, starts by pressing the "Start" button on the screen of the Analyzer module. Then, the system asks, in a synthesized voice, the patient's anxiety level. The participant, in turn, responds by voice, indicating their anxiety level on a scale from 0 to 10 (SUDS scale). The system analyzes the given response and the obtained heart rate and calculates the resulting anxiety level via the Fuzzy module. If the anxiety level is considered "High", the system will not start the presentation of the virtual environment to the volunteer. If the initial calculated anxiety level is "Low" or "Medium", the system will allow the presentation of VR videos. Once the virtual environment execution begins, the system checks the volunteer's pulse every 15 seconds. If the pulse reaches 105 BPM, the system will pause the execution and ask again for the volunteer's anxiety level, preventing continuation whenever the calculated anxiety level is considered "High", If manual intervention is needed during the session, the system allows pressing the "Stop" button on the Analyzer agent's screen (Figure 8). This activation re-executes the pause routine, asking again for the volunteer's anxiety level. This feature is particularly useful for cases where a high anxiety level is perceived, even if the pulse has not reached the 105 BPM limit.

Regarding the 3-D environment, two sequential videos were selected. The first video shows a waterslide (Figure 9) where the volunteer perceives themselves going through a course with various curves, ascents, and descents. The second video presents an airplane flight (Figure 10) where the volunteer feels like they are flying over a city. The transition from one video to another is conditioned by the anxiety level calculated by the system, as the goal is to simulate the stages of desensitization of a patient concerning the presented phobic stimulus. At the end of each video, the system informs by voice that it will move to the next stage. Once all stages are completed, the system announces that all stages are finished.

The complete execution script of the system can be seen in Appendix A (Figure 14), where the activity diagram of the system's agents is presented.

6 System evaluation

The PhobIA 3DS evaluation project was approved by the Ethics Committee of State University of Rio de Janeiro, protocol no. 6.104.588. Six volunteer psychologists used the system in their respective professional practice locations. After the evaluation session, they received a Google Forms link to answer a questionnaire with questions related to their profile, as well as questions regarding the usability, interface and relevance of the PhobIA 3DS system.

Data regarding the profile of volunteers revealed that they are individuals with considerable experience in the field of behavioral psychology. The age range of the participants was between 31 and 60 years, accounting for 66.6%. Regarding occupational therapy practice, 50% of the professionals indicated that they work with this approach, meaning half of the evaluated sample. All participants work privately, not affiliated with any public institution. Concerning personal experience with computational technologies, 83.3% of the participants reported experience, and all stated that they use computational and communication technologies with their patients. Considering primarily the reported professional experience and the frequent use of computational technologies, the result of this evaluation stage highlights the importance of these professionals' opinions regarding the PhobIA 3DS system.

There are many techniques and dimensions to consider when evaluating a product. For this initial PhobIA 3DS assessment, three dimensions were considered: usability, relevance to the health sector, and the interface. Usability is a fundamental aspect of systems used in the health areas, considering the risk factors involved. The system must be simple and effective for everyone, regardless of the users' levels of understanding [Zainab *et al.*, 2023]. The relevance for professionals in the application area is fundamental for observing the potential adoption of the system.

The instrument for observing the relevance dimension has three questions and qualitative items to identify users' perceptions of the software's utility. The interface evaluation considered seven questions to observe the perceived quality of the dynamics adopted in PhobIA 3DS: issues in oral communication, occurrence of dizziness, and delays in scenes generation.

The System Usability Scale (SUS) was used to evaluate usability. This questionnaire proposes 10 statements about the product, formulated alternately in affirmative and negative forms. Responses are given on a Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree) [Bangor *et al.*, 2008]. If the final score is below 35.7, the rating is considered poor, while scores higher than 71.4 are considered good, and above 85.5 are excellent.

In Tables 5, 6, and 7, the evaluation instruments for the categories "Relevance", "Interface" and "Usability" respectively, are presented, as well as the results obtained after the questionnaire was completed by all participants.

6.1 System evaluation results

For the sake of a more visually intelligible evaluation, three graphical visualizations of the weighted average results obtained for each item in each evaluation category were produced (Figures 11, 12, and 13), where it is possible to see the resulting graph for each questionnaire item.

A preliminary consideration is necessary before evaluating the items answered by the volunteers. In SUS instrument there are statements where the higher the value given (up to a maximum of 4), the better the system is evaluated in the respective criterion. Conversely, other statements represent a better evaluation of the item as the value approaches zero.

To obtain an initial overview of the relevance and quality of the interface, and given the small number of participants,

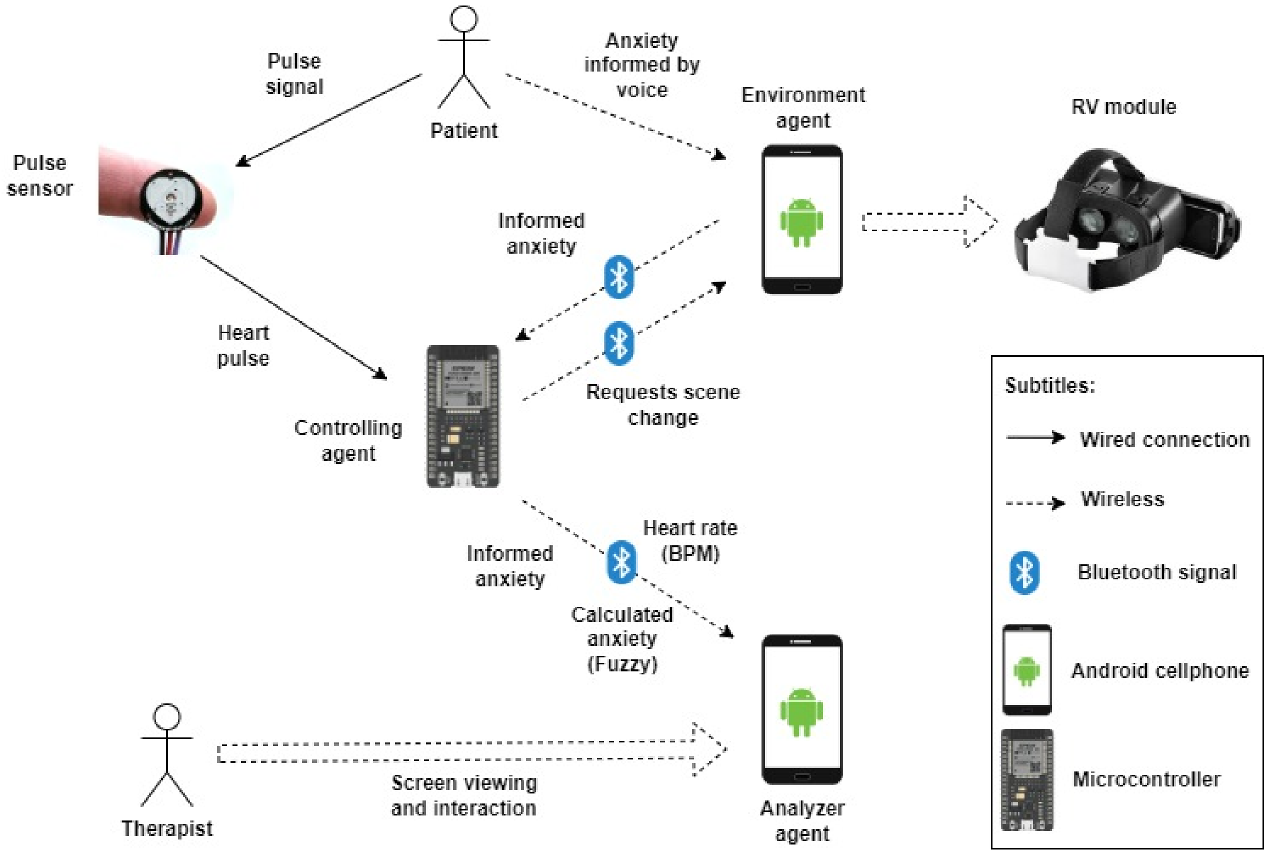

Figure 5. Agent communication and interaction diagram.

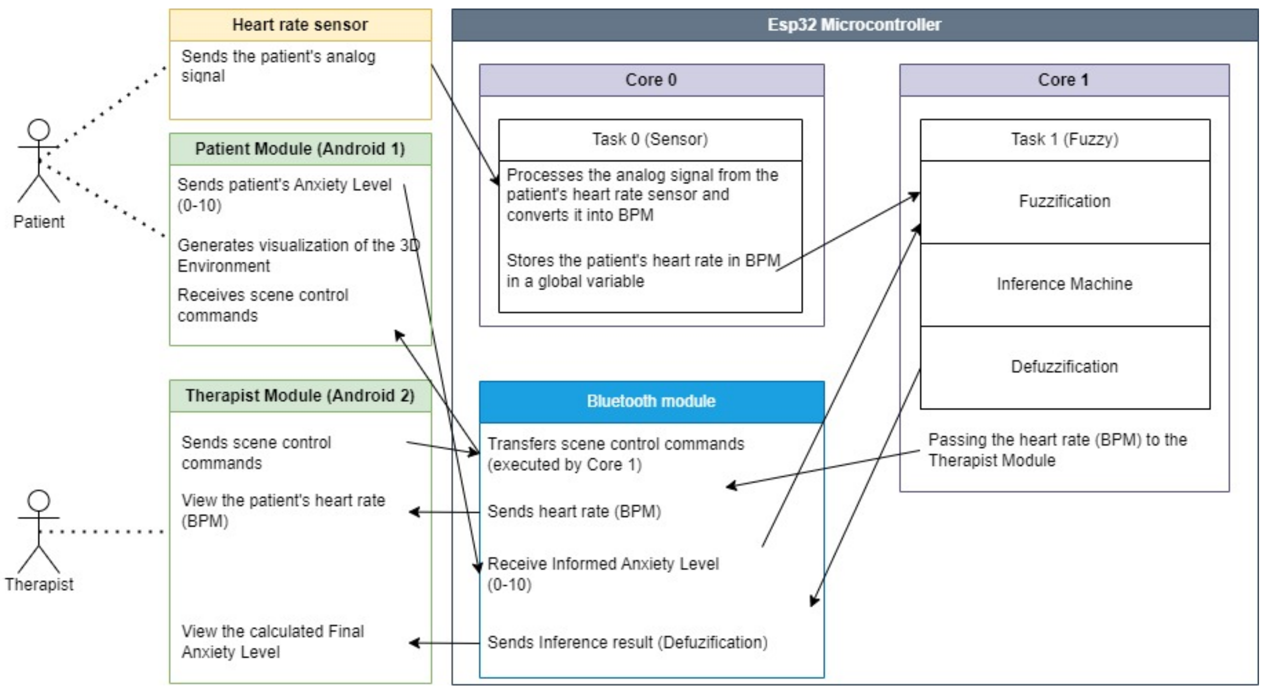

Figure 6. Software, human-agent and hardware integration flow.

Table 5. System Relevance Assessment Instrument.

Evaluation Item	Strongly disagree	Partially disagree	Neither agree nor disagree	Partially agree	Strongly agree
1- The system has the potential to reduce patients' stress levels.	-	1	-	4	1
2- The system can serve as a complement to traditional therapy.	-	-	-	1	5
3- The use of the system would facilitate the desensitization of specific phobias.	-	-	-	3	3

Table 6. System Interface Evaluation Instrument.

Evaluation Item	Strongly disagree	Partially disagree	Neither agree nor disagree	Partially agree	Strongly agree
1- The virtual therapist's speech is clear and easily understandable.	-	-	-	1	5
2- The scenes presented are appropriate to the system's objectives.	-	-	-	2	4
3- The voice communication method is simple and effective.	-	-	-	1	5
4- The therapist module's interface includes important items for monitoring the patient's progress.	-	-	-	1	5
5- There were delays in presenting the scenes.	6	-	-	-	-
6- The interaction dynamics with the system worked well.	-	-	-	1	5
7- I felt comfortable using the system, without dizziness or nausea.	2	-	-	-	4

Figure 7. Initial testing of the system in its final assembly.

we will observe Figures 11, 12 and 13. In this case, the figures shows high scores for the analised items in all three dimensions.

Figure 11 presents the results on the system's Relevance. All items correspond to statements where the best evaluation result will be the closest to 4. To stress the system's potential for treating some phobias, the most important result is that they considered that the system can be viewed as a complement to traditional therapy, opening new treatment scenarios.

In Figure 12, we draw attention to item number 5, formulated negatively. In this case, lower values indicate a positive result. The participants considered that the Phobia 3DS system has scenes appropriate to the system's objectives, voice communication is efficient, and there are no delays in the presentation of scenes.

The SUS scale, whose results are presented in Figure 13, is formulated with alternating affirmative and negative propositions. In propositions 2, 4, 6, 8, and 10, represented in yellow, the lower the value, the more positive the result. In propositions 1, 3, 5, 7, and 9, represented in blue, the higher the value, the more positive the result.

In the usability evaluation of the system using the SUS, the calculated result was approximately 86.67. Considering that the calculated value is above 85.5, the system was classified as "Excellent" in terms of usability.

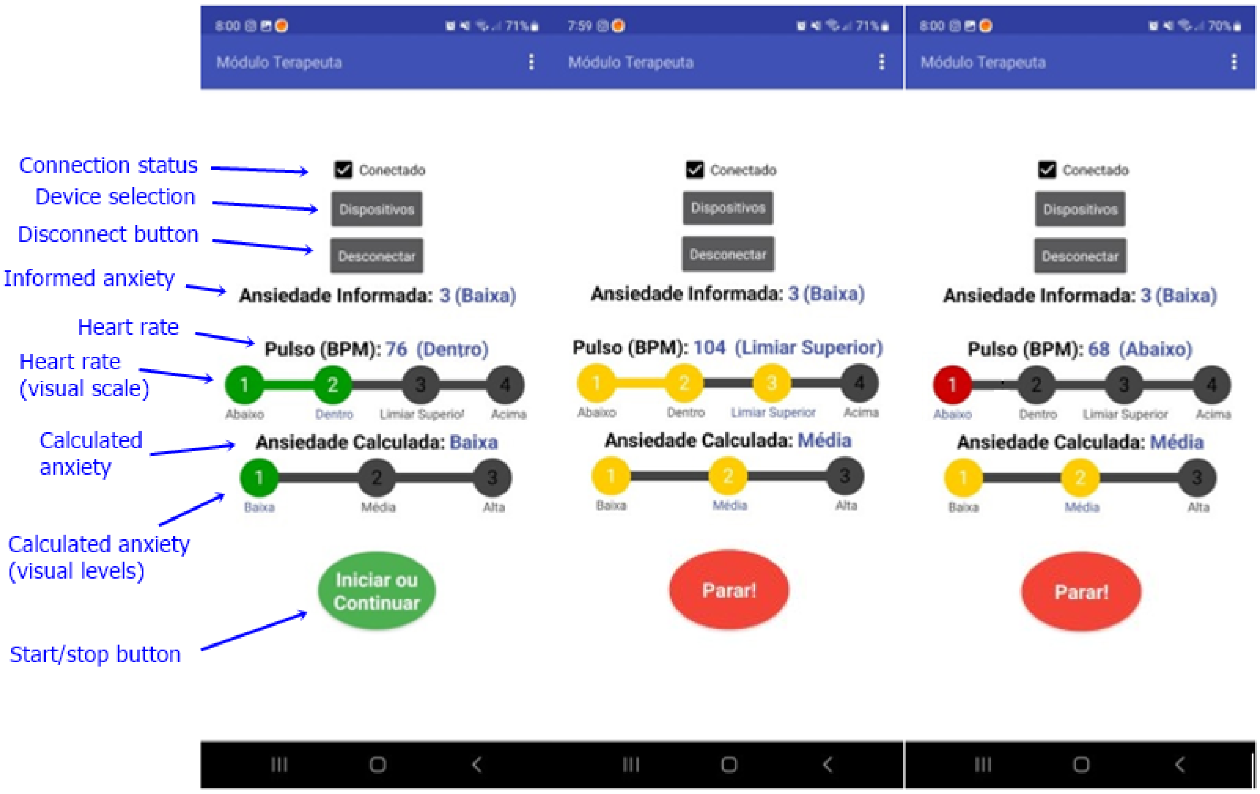

Figure 8. Main screen of the Controller agent (Therapist Module) being presented in three different measurement situations.

Figure 9. 3-D Video Slide [360 Vacation VR , 2018].

Figure 10. 3-D Airplane Video [S Gaming VR, 2023].

7 Conclusion

This work aimed to present a low-cost technological combination embedded in an ESP32 board, with multi-agent control and Fuzzy Logic, supported by natural language communication, to be used in the field of Clinical Psychology related to Anxiety Disorders. The prototype was built using low-cost technologies and, in most cases, open-source code. At the time of the completion of this work, the system had a final cost of approximately $50 USD, excluding smartphones.

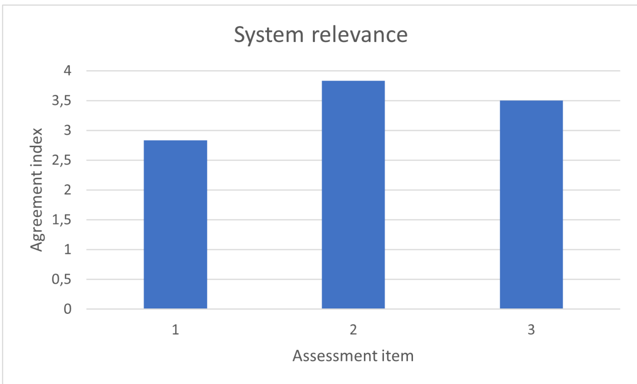

Figure 11. Average of the results obtained in each proposition in the “Relevance” dimension.

As contributions, this work created an integration of AI technologies in an ESP32 microcontroller that can be connected to a smartphone attached to low-cost goggles, opening up perspectives for the use of affordable technologies in phobia treatments.

The notable difficulty encountered during the development of this work was the integration between the various software and hardware technologies involved. Another difficulty was the scarcity of works to be used as a reference in the prototype development, specifically about the Esp32 microcontroller in applications aimed at virtual reality. In several situations, during the prototyping steps, it was necessary to look for programming alternatives to avoid the use of paid software components, especially in the case of communications via Bluetooth signal. Regarding assessing the system by volunteers, a difficulty was the occurrence of the

Table 7. System Usability Scale Evaluation Instrument.

Evaluation Item	Strongly disagree	Partially disagree	Neither agree nor disagree	Partially agree	Strongly agree
1- I would like to use PhobIA 3DS frequently.	-	-	4	1	1
2- I find PhobIA 3DS unnecessarily complex.	5	1	-	-	-
3- I found PhobIA 3DS easy to use.	-	-	-	1	5
4- I think I would need help from someone with technical knowledge to use PhobIA 3DS.	2	4	-	-	-
5- I think the various functions of PhobIA 3DS are well integrated.	-	-	1	2	3
6- I think PhobIA 3DS has too many inconsistencies.	5	1	-	-	-
7- I think people will learn to use this system quickly.	-	-	-	2	4
8- I found PhobIA 3DS complicated to use.	5	1	-	-	-
9- I felt confident using PhobIA 3DS.	-	-	2	-	4
10- I had to learn many new things to use PhobIA 3DS.	2	3	1	-	-

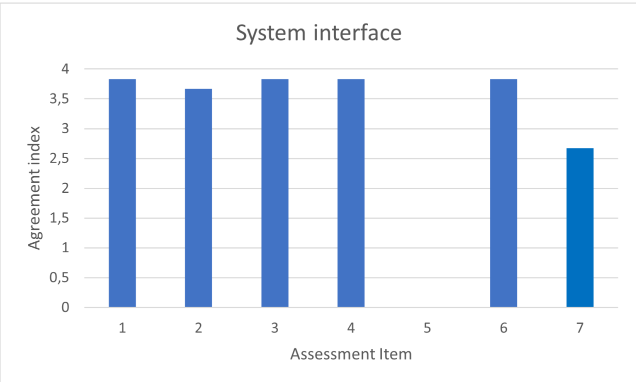

Figure 12. Average of the results obtained in each item in the "Interface" category.

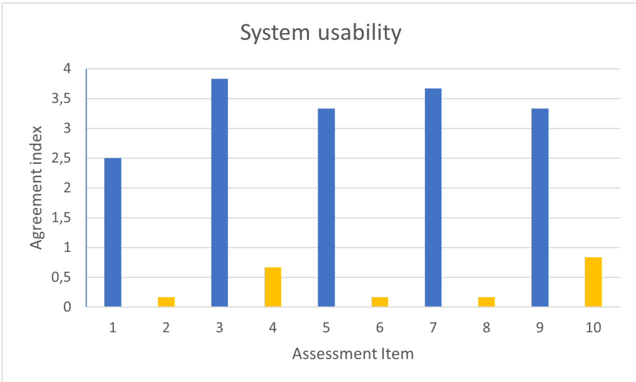

Figure 13. Average of the results obtained in each item in the "Usability" category.

so-called Cybersickness. This condition is a limiting factor for the use of the system, and it cannot be perceived previously if an individual will suffer this effect, except in cases of reports or problems such as labyrinthitis.

Another aspect related to Cybersickness is age because people over 40 years have a higher prevalence of symptoms associated with motion sickness, and applications with a smaller viewing angle have a higher prevalence of problems [Ramaseri Chandra *et al.*, 2022]. Our application has a limited viewing angle due to the width of the smartphone screen, which can cause more problems associated with Cybersickness.

In a recent work, Slater *et al.* [2022] proposed a relevant discussion that has not yet been explored in the context of this research. The authors discussed the concept of presence. In the context of this subject, we think that PhobIA 3DS can be used to assess some of these questions to verify whether the patient's anxiety level does not change because he does not capture the stimuli provided by the scenes presented, or whether he is using an avoidance behavior strategy to prevent his suffering.

For future evaluations with people with phobias, validated questionnaires such as those cited by Binder *et al.* [2022] will be considered, which are specific to assess anxiety levels after using the system. However, the PhobIA 3DS proposal has a different approach. It uses the combination of heart rate with the anxiety level provided by the patient and, with the support of Fuzzy Logic, identifies in real-time the increase or decrease in the anxiety level. In this case, if this inference indicates an increase in the anxiety level during the use of the system, it is possible to interrupt the session or reduce the level of stimuli provided to the patient, avoiding their suffering.

In future work, we intend to place a relaxation module in case the level of anxiety rises significantly, in line with what Kosonogov *et al.* [2023] proposed. According to the authors, many studies have shown that virtual environments can induce a wide variety of emotions, and the use of additional psychotherapeutic intervention techniques, such as relaxation techniques, can alleviate stress problems during virtual sessions.

As threats to validity, we can mention the low number of scenes used in the tests, which may not have been sufficient to assess the increase or decrease in stimuli related to the patient's stress level. Other aspects that can be mentioned are the small sample size and the use of personalized scales in the assessment.

A potential future application of the PhobIA 3DS system, in addition to the treatment of specific phobias, would be its use in training programs for professionals who need to perform tasks requiring more control over anxiety levels during procedure execution.

Declarations

Authors' Contributions

Claudio H. M. Jambo: Research, hardware and software development, concept design and development, experimental execution, writing, and review. Rosa Maria E. Moreira da Costa: General review, writing, guidance on research methodology and concept and design development. Vera Maria B. Werneck: Review, writing, and guidance in Software Engineering.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Data can be made available upon request.

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A Appendix A

See Figure 14.

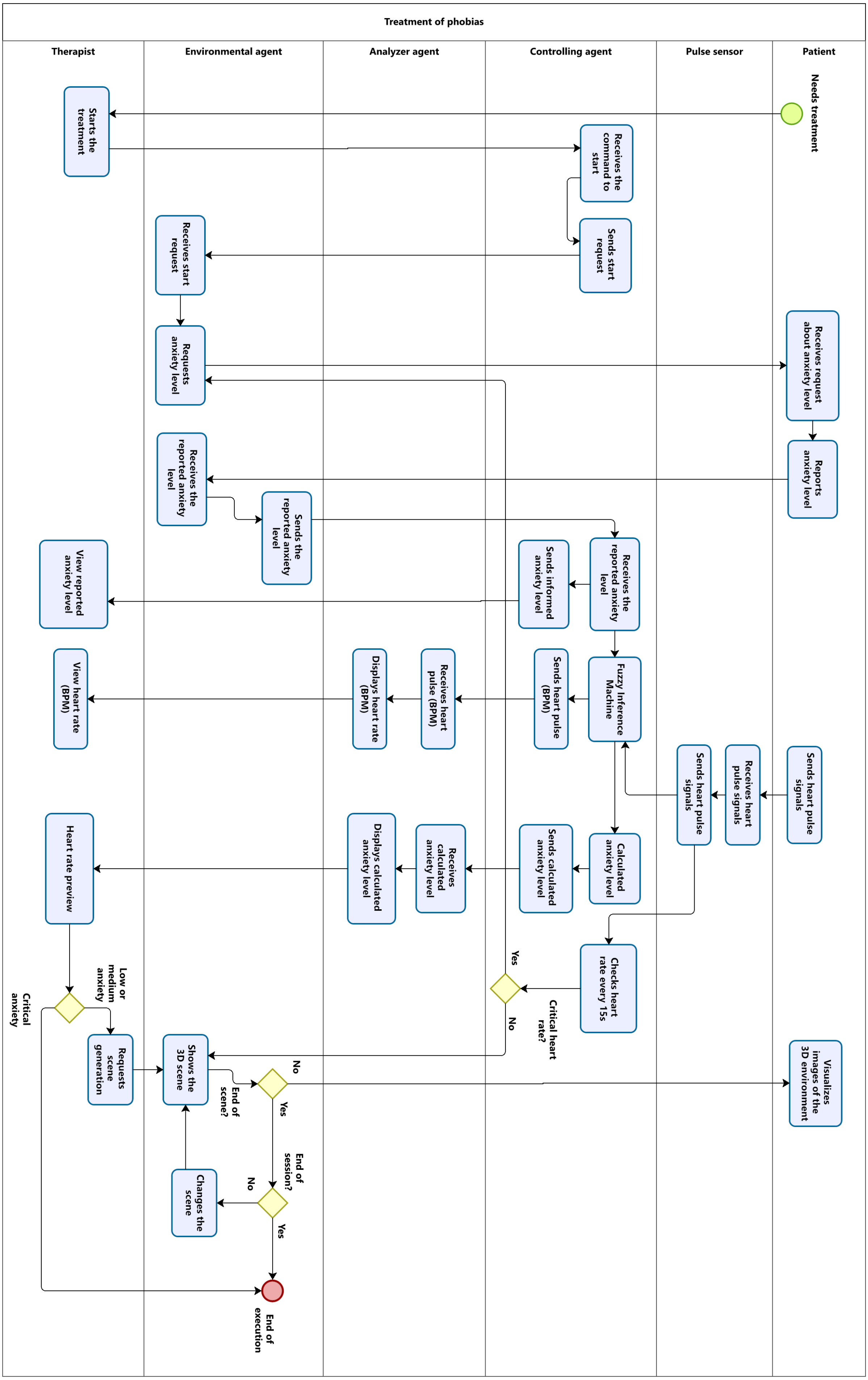

Figure 14. Activity diagram of the agents in the PhobIA 3DS system.