

MedTech Simulator – A tool for medical students

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Abstract. Socioeconomic and health system progress has resulted in significant improvements in living conditions and an increase in average life expectancy. However, the aging of the European population highlights the growing demand for healthcare. Technology plays a crucial role in transforming this sector, driving advances in the treatment and diagnosis of diseases. Medical simulation emerges as an essential tool for improving skills, facing challenges in the transition to more effective and realistic approaches. The shortage of trainers and supervision during internships are challenges in medical education in Portugal, as well as preventable deaths related to medical errors. In response to these problems, the MedTech Simulator, an advanced training tool designed to improve the technical skills of medical students in a safe and realistic way. With a clinically accurate environment, the simulator integrates crucial functionalities such as facial recognition, speech processing, motor-controlled head and eye movements, and pressure, temperature and breathing mechanisms. The interface offers disease simulation options, allowing control of each module and visualization of vital data. The harmonious integration of Python, Arduino Mega and Raspberry is essential to the success of the medical simulator. The purpose of the prototype is to guarantee the appropriate knowledge, skills and behavior of doctors in clinical training, to provide excellent service and ensure patient safety.

Keywords: Medical Simulation, Medical Training, Robotics, Medicine, Technology.

1 Introduction

Health is a sensitive topic for society, due to the implications it has at a political, economic and social level, and is under permanent scrutiny. The evolution of health systems, housing conditions, basic sanitation, work, nutrition and the implementation of a sustainable social network [Cabral et al, 2013] led to a decrease in mortality that contributed to the increase in the average life expectancy of Portuguese people from 63 years in 1961 to 81 in 2011 [Dixe et al, 2018]. It is estimated that, by 2024, Europeans over 65 years will surpass young people under 15 [ONU], revealing a greater need and demand for health care [Alves et al., 2015]. It is expected that the number of patients will grow exponentially. In this way, the time to respond to problems and resolve them tends to shorten, making it necessary to formulate strategies and adapt sufficient

resources to meet the level of demand for assistance [Aveni, 2020]. Given the limitations of the healthcare system and the rapid aging of the population, there is a need to redefine healthcare policies [Wong et al, 2006]. Technology has played a fundamental role in each century, with the main advances being related to the acquisition, processing and dissemination of information [Macedo et al, 2018]. In this sense, technological advances in the health sector occurred due to the introduction of information technology and the appearance of modern and sophisticated devices that benefited the fight against diseases [Barra et al, 2006]. There is international recognition of the need for change in the training of health professionals, since the current teaching method does not keep up with technological innovations. Educational institutions have been encouraged to evolve towards teaching that values quality and efficiency in the provision of health services. The process of changing education brings numerous challenges, including the rupture of traditional teaching models, to train professionals with transversal skills [Eliana Cyrino et al, 2004]. Traditionally, patients were used as the main source and object of medical education. The expression "never the first time for the patient" emphasizes the importance of teaching through medical simulation, being defined as a technique to simulate real experiences in an interactive way [Pezel et al, 2021]. Ensuring the appropriate knowledge, skills and behavior of doctors in clinical training is crucial to providing excellent service and ensuring patient safety. In this way, during the internship, an experienced doctor guides and supervises the work and progress of each intern, in accordance with the specific learning objectives established for each clinical internship [Marianne Kleis Mølleret et al, 2022]. Currently, in Portugal, medical education faces several challenges, with the number of medical students clearly exceeding the number of doctors with training capabilities to teach. The consequence of this situation will only worsen in the near future, with the departure of doctors from the national health system. It is concluded that there is a lack of trainers, due to the growing number of doctors leaving public institutions [João Paulo Farias, 2017].

Industrialization brought with it, in addition to modernization, technological advancement and the appreciation of science [Barra et al, 2006]. Innovations in healthcare education, together with technological advances, have given rise to increasingly sophisticated simulators, sparking interest in medical simulation [Lemos et al, 2016]. Therefore, medical simulators are becoming a fundamental element in the educational services offered to medical students, nursing students and healthcare auxiliary professionals. Increasingly, medical programs are combining traditional classroom with hands-on teaching, turning to computer-based simulators to gain efficiencies in terms of time, costs and resources, thus supporting effective completion of necessary training [Kunkler, 2006]. In this sense, preventable deaths related to medical errors demonstrate the need to improve medical training to reduce risks [Pezel et al, 2021]. There is also a growing demand for specific treatment services and a reduction in the number of hours doctors can work per week [Kunkler, 2006]. Therefore, ensuring patient safety and preventing medical errors is crucial for maintaining healthcare systems [Pezel et al, 2021].

2 State -of-Art

2.1 Simulation Types

The first medical simulators were simple models made from sheep's lungs and liver, used by temple priests in ancient Mesopotamia to instruct disciples and predict the course of future events. Over time, these basic models evolved and were used as diagnostic tools to demonstrate the clinical characteristics of certain diseases [Kunkler, 2006]. Currently, there are several devices created and implemented to ensure that hospital work is as efficient as possible. Thus, there are highly sophisticated mannequins that are available to support medical teaching. These are automated human simulators, capable of reproducing tactile, sound and visual responses, similar to those that doctors must witness in contact with real patients, but in a way that can be controlled and modified by the operator [Romano et al, 2007].

Simulations provide a means to obtain a variety of experiences, including skill development, pattern recognition, problem solving, diagnosis, and treatment. Thus, they can be used to complement and, in some cases, replace conventional learning experiences. These can eliminate the need for a real laboratory or patient, reduce students' inhibitions, and allow for a broader range of possible experiments. Simulations can provide experimental setups in cases where it is impossible or unethical to perform the experiment on real patients. In a simulated environment, students can see the response to changing a single parameter in a controlled way, which is not possible in living materials [Bergeron et al, 1988].

2.2 Software Medical Simulation




Current training techniques include traditional teaching materials, virtual training scenarios, manikin simulations with and without physiology, and live patient simulations. However, current training methodologies have significant limitations. Expert feedback is needed before, during, and after the clinical scenario to ensure accurate physiological responses are provided to the trainee. This significantly limits the number of trainees with access to high-quality training. Virtual physiology engines, both open source and proprietary, offer a powerful alternative [Bray et al, 2019].

2.3 Medical Simulation by Mannequins - High-Fidelity vs Low-Fidelity

The use of high-fidelity simulators has been incorporated into clinical teaching in recent years. This offers students the opportunity to improve clinical skills in a safe and realistic environment. These provide an environment with a high level of precision and clinical reality, allowing participants the opportunity to put into practice the skills acquired in the classroom. With a team approach, it is possible to apply knowledge from theory to practice [Hill et al, 2023]. In simulation training, there is an approach to reality where trainees are expected to react to problems or conditions, as they would do in real contexts [Munshi et al, 2015]. Compared to high-fidelity simulators, low-fidelity simulators are essential for education, because they allow the student to learn at their own

pace, facilitating practice in a safe environment without risks for the patient. From a cost-effective perspective, manikins are less expensive and are easily transportable, making them more accessible to students in hospitals or universities [Hill et al, 2023].

Table 1. Advantages and disadvantages of Existing Simulators.

Simulators	Benefits	Disadvantages
 <p>HARVEY</p>	<p>Accurate recognition of critical signals in simulations. [Jones et al, 1997]</p>	<p>Difficulty in establishing a correct diagnosis for simulations of three types of valve diseases [Jones et al, 1997]</p>
 <p>AMBU MAN</p>	<p>Wireless control from a web browser. Self-expanding bag and face mask. It is possible to train the placement of devices in the airways, such as the laryngeal mask airway [Schram, AL et al, 2022].</p>	<p>Lack in reliability of dummy for chest compressions and ventilation. Difficulty in learning how to properly operate the simulator [Silva, LDB, 2023]</p>
 <p>CAE Apollo</p>	<p>Wireless with exclusive software. Capable of simulating a huge variety of processes physiological humans as well as the study of its correct handling [Gudadappanavar et al, 2023].</p>	<p>Knowledge and support in terms of the software used is necessary due to its complexity [Gudadappanavar et al, 2023]. High cost [caehealthcare]</p>

3 Materials and Methods

This section contains the functional requirements of the medical simulator, where its characteristics and applied logic are presented and described later in the topic Hardware, the components used are listed, as well as the method of application and communication between them.

3.1 Functional Requirements

The overview of the system, represented in figure 1, includes a medical simulator on a mannequin (A) intended for medical students to train patients in analysis (C) and diagnosis (D) during their academic and clinical training. The main focus is the training of doctors with transversal and excellent skills, in a controlled environment (E). The simulator can interact with the doctor, communicating symptoms (F), and responding to visual stimuli (G). Finally, this allows the use of an oximeter and armband (I), and

the measurement of body temperature (J). The simulator offers the ability to simulate several diseases, including Acute Bronchiolitis, Acute Myocardial Infarction and Chronic Obstructive Pulmonary Dis-ease. These were carefully selected so that the parameters relating to blood and systolic pressure, oxygen level, respiratory rate and temperature are different from the standard values of a healthy person. This is important to be able to simulate different conditions and the training to be specific. The simulator becomes sensitive to visual and auditory stimuli, activating sound sensors, facial recognition and eyes, controlled by neck motors and the eye mechanism. The eyes blink and move, fixating on an individual through facial recognition. When a medical student starts a dialogue with the simulator, it responds, starting a conversation and moving its mouth synchronously. The interaction between the student and the simulator plays a crucial role in improving clinical skills and developing diagnoses. These dialogues have been carefully pre-defined to simulate realistic clinical situations, offering students the opportunity to practice and improve their communication and assessment skills. Thus, they recreate authentic clinical scenarios, addressing pertinent issues for each simulated pathology, such as clinical history, symptoms and risk factors.

To monitor vital signs, a tension measuring arm, and an oximeter are used. The simulator displays the corresponding values by activating the pressure sensors. Furthermore, if the selected disease includes the manifestation of fever, the simulator, through a ceramic heating element, recreates a more complete and realistic experience for the student during clinical training. This interactive, multifaceted approach provides a comprehensive simulation of selected medical conditions, enriching the learner and training exercise experience. The interface allows you to add diseases and add respective clinical cases for each disease. Each clinical case had the patient's personal information, medical history, conditions to be simulated and medical observations.

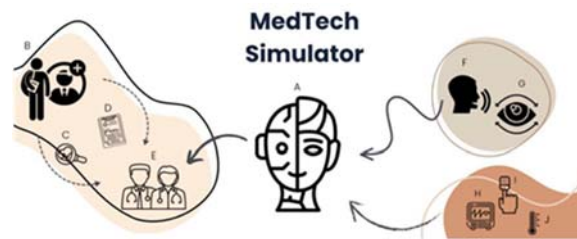


Fig. 1. MedTech Simulator architecture.

3.2 Hardware

In the context of the development of the medical simulator, specific modules were developed for hardware intended for its construction. To achieve this purpose, several types of motors were required, including servo motors, stepper motors and continuous DC motors. Additionally, pressure and sound sensors were incorporated, along with a thermostatic ceramic component for heating and a relay. All these components establish communication with both the Arduino and the Python, being coordinated to simulate,

in an integrated way, a certain medical condition. The project block diagram is below (Fig. 2).

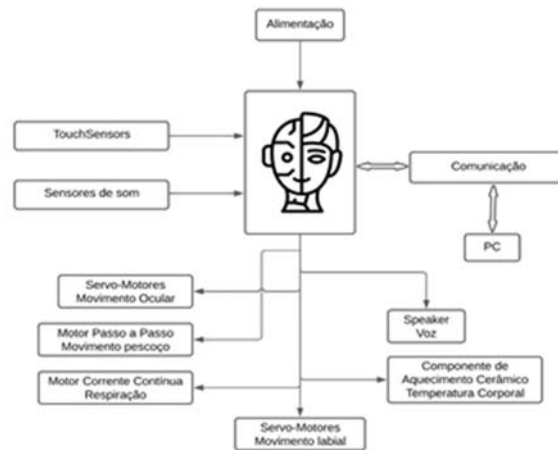


Fig. 2. Project Block Diagram.

Breathing Simulation - Continuous DC Motor. Manages the movement of the motor based on the given parameters, such as forward and reverse speed, and corresponding times. The motor has a torque that allows it to move a structure. This mechanism inflates the balloon, making the air pass through tubes to the head of the medical simulator, simulating breathing. Its operation is continuous throughout the simulation, functioning independently of all other components.

Head Rotation - Stepper Motor. The control logic takes a simple approach by comparing disparities in sound intensity between sensors. The engine is activated when these differences exceed a predefined limit. This implies that the engine only reacts to considerable sound variations, avoiding unnecessary movements in response to small fluctuations in the sound environment. The discrepancy between the maximum value and the average can be interpreted as an indicator of variation in the data collected during the reading period. A considerable difference suggests the occurrence of at least one notable peak in the sound across the reading interval. Subtracting the average from the maximum value helps filter out short-term fluctuations and noise, focusing on the most significant spikes.

Eye and mouth movement – Servo motors. This mechanism simulates the movement of the simulator's mouth when a dialogue is initiated. The prototype eyes are made up of six servo motors: two that perform horizontal/vertical movement, and two servo motors for each eyelid of each eye. Each motor is responsible for a specific movement, when coordinated, they simulate eye movement, such as blinking, looking right and left. The parts that make up this structure were taken from a prototype already

developed and designed to work with a joystick, however, as this was not the objective of our project, it was appropriately adapted [M.A.I., 2019].

Vital Signs Monitoring - Pressure Sensors. When the oxygen sensor placed on the mannequin's finger is activated, its status is displayed on the serial terminal. A message is sent to Python indicating that it is activated, and, on the interface, the oxygen values are shown depending on the simulated disease. The pressure sensor located on the mannequin's arm works in a similar way, if it is active, the blood pressure values are highlighted.

Body temperature simulation - relay and ceramic heating component. This system is controlled via serial communication between Python and Arduino. Using pre-defined values "0-deactivate" and "1-activate" the Arduino can control the current that passes through the ceramic heating component. This approach enables precise thermal control, heating or cooling as needed.

Printed circuit board. Designed with the aim of simplifying Arduino connections and reducing the number of Arduinos used to one. Apart from the breathing system that works independently.

3.3 Software

This section explains the connection and communication mode between all hardware components. To this end, a program was developed in Python which ensures the entire functioning of the medical simulator, from choosing the disease to simulate, activating each module, until deactivating it. Two fundamental algorithms that allow dialogue between the user and the simulator, and facial recognition by the latter, are also enunciated and described. Speech simulation is based on an algorithm based on the library `speech_recognition` which converts audio to text. Audio capture is performed by a microphone, indicating to the user when to start and stop speaking. The algorithm offers effective transcription functionality, ensuring linguistic accuracy during the process. The library `OpenCV` enables real-time facial detection and recognition. The simulation starts with facial recognition. Regarding the project interface, after starting the simulation of each clinical case, the temperature status of the disease is evaluated to check if it is supposed to simulate fever. Next, the facial recognition process begins. At this moment, the motor moves according to the sound and, when it detects a human face, it stops and starts to follow the person's movements. After this process, the simulation itself begins, allowing the user to activate sensors to obtain the oxygen saturation level and pressure values. The values are generated from a base value (detailed in the clinical case). With this value, close values are generated. These values are represented graphically and numerically. Furthermore, there is a graphical representation of respiratory rate values, although this is not used to change the state of physical breathing.

4 Results and Discussion

The results presented are observations and conclusions that come from various tests carried out throughout the development of the features and each module, with the aim of analyzing their difficulties and successes. This section reflects the practical effectiveness of MedTech Simulator as a medical simulator capable of interacting with users, with the main objective of improving medical training by reducing risks and errors. Regarding the breathing mechanism, it proved capable of simulating air flow similar to a human respiratory system. The simulator's mouth proved to be effective in simulating lip movement during speech. However, a possible future improvement would consist of making this process more realistic, incorporating a greater diversity of angles and movements and another type of structure. The pressure sensors demonstrated a satisfactory response to touch, truly allowing the user to simulate the measurement of pressure and oxygen when the medical devices are placed in the appropriate locations. Fever simulation is a mechanism that can be improved to effectively achieve high temperatures through the ceramic heating element. However, the temperature sensor was removed due to fluctuation in values in relation to the actual temperature. Therefore, it would be advisable to use a more sensitive and precise sensor to improve measurement accuracy. In relation to the face, which comprises the eyes, mouth and nose, an approximate shape of a human being was expected, allowing for a more realistic interaction with the patient. However, by placing a mask, the movement of the servo motors would be restricted. Later, by building a structure around these elements to protect them, the human form can be achieved. Regarding the graphic interface, an essential improvement would be the implementation of databases for facial recognition and for diseases and clinical cases so that all information is stored in a simple and secure way. Despite all possible improvements, the final prototype was achieved as well as all its initially designed modules, as referenced in Fig. 3.

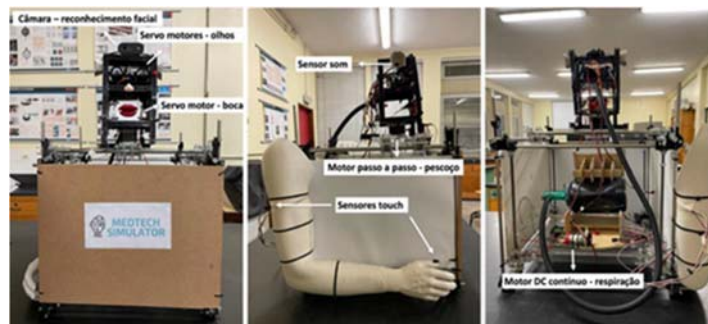


Fig. 3. Final Prototype.

5 Conclusions

The MedTech Simulator represents an innovative approach designed to enhance the technical skills of medical students in a secure and realistic environment. This simulator

offers a clinically accurate setup that closely mimics real-life interactions between patients and doctors. It integrates several critical features essential for simulation training, enabling students to respond to various medical conditions effectively. The originality of the MedTech Simulator lies in its comprehensive integration of advanced technologies. Unlike traditional simulators, the MedTech Simulator employs Python, Arduino Mega, and Raspberry Pi to achieve a seamless and interactive experience. This ensures that medical students can practice in a controlled environment that closely replicates real clinical situations. The MedTech Simulator addresses the existing challenges in medical training, particularly the shortage of trainers and supervision during internships. By providing a realistic and interactive training tool, it minimizes the risks associated with medical errors and improves patient safety. In conclusion, the MedTech Simulator represents a significant advancement in medical education technology. It not only offers an innovative solution to the limitations of current training methodologies but also ensures the development of proficient medical professionals. The successful integration of hardware and software elements marks a substantial contribution to the field, promising to enhance the quality of healthcare education and patient care. However, there is ample room for further improvement and refinement. One notable area for enhancement is the face-tracking movement, which could be made more responsive and accurate. Additionally, synchronizing eye and lip movements with each other and with speech could be refined to offer a more realistic simulation. Currently, the simulator's chatbot is limited to predefined conversations and lacks the capability for interactive dialogue, an issue that could be addressed by incorporating the latest AI technologies. Furthermore, the movements (eye, lip, neck), while functional, could be smoother to better mimic natural human motions. The breathing module, which currently only allows for adjustments in airflow speed, could benefit from additional functionalities to simulate a wider range of respiratory conditions. These improvements would further enhance the realism and educational value of the MedTech Simulator, making it an even more powerful tool for medical training.

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