Heart Failure Diagnosis VR Simulator

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***Abstract*—This paper presents a virtual reality (VR) simulator for the treatment of a virtual patient with heart failure condition. The proposed simulator is composed by a VR headset with tracked controls and a virtual environment of the doctor's office and a examination room with the specialized equipment for the diagnosis. The entire workflow of the simulation is based on a graph derived from the heart failure guidelines of American Heart Association. A preliminary human factors study demonstrates the potential use and applicability of the prototype for clinical training.**

***Index Terms*—Heart failure, virtual reality, simulator**

I. Introduction

Heart Failure (HF) has a universal definition widely disseminated since 2021, it is a clinical syndrome characterized by cardinal symptoms: dyspnea, ankle edema and fatigue, which are accompanied by signs such as elevated venous pressure, pulmonary rales and peripheral edema [2]. It can be caused by structural or functional abnormalities that generate high intracavitary pressures and/or inadequate cardiac output, both at rest or during physical activity. HF causes the heart muscle to not be able to pump enough blood as it should to support other organs in the body.

The prevalence of this disease is between 1-3% of the population, being higher in men and having an incidence of 1-20 cases per 1000 person-years or per 1000 population [1]. In the United States of America more than 6.2 million adults were affected by HF in 2020 [12].

In recent years, the prognosis has improved substantially thanks to new drugs, new intracardiac devices, and the possibility of advanced therapies such as transplantation and mechanical ventricular assistance. Nevertheless, mortality remains high because 1^{st}-year mortality is approximately 10%, and 5^{th}-year is about 50%. The annual healthcare costs for this disease are high and can exceed €25,000 per year in Western countries and are expected to continue increasing, depending on the geographical area and the comorbidities of the population [1].

One strategy to reduce mortality and hospitalization with a better patient recovery is to promote and encourage training in HF. It is necessary to optimize medical education tools and promote scenarios that motivate and improve the skills of doctors in training to be able to more accurately diagnose and manage patients with HF. Simulation in cardiology permits to achieve learning outcomes through experimentation in a safe lifelike artificial environment [8]. VR simulation for cardiovascular diagnosis and treatment permits the training in high fidelity environments as reported by [3], [10], [11].

In this paper, a VR simulator for HF diagnosis with a virtual patient is presented. In the simulation the user, a cardiology resident, can examine a virtual patient to identify the symptoms of HF, perform the relevant tests and issue a diagnosis with the initial treatment. This paper is organized as follows: Section II describes the methodology used for the study. Section III discusses the results. Finally, section IV presents recommendations and future work.

II. Prototype Development

HF diagnosis requires the evaluation of various parameters obtained by strategies such as patient assessment, blood tests, electrocardiogram and transthoracic echocardiography among others [5], [6]. For this VR simulator, an algorithm with all the steps for diagnosis is required in order to have a successful and valid learning experience.

A. Diagnosis algorithm

A diagnostic algorithm for classification of HF is presented in the 2022 AHA/ACC/HFSA guidelines for the management of HF [5]. This algorithm was adapted for the simulator as follows:

1) Patient assessment (anamnesis) and basic clinic. Evaluation of clinical history for conditions such as high blood pressure, myocardial infarction, shortness of breath and exhaustion. Electrocardiogram.
2) Perform a blood test in the laboratory including Natriuretic Peptide tests (BNP, NT-proBNP)
3) Perform an transthoracic echocardiogram to assess the percentage of left ventricular function fraction, and according to the results, classify the HF in reduced, slightly reduced or preserved.
4) Propose medical treatment.

B. Algorithm programming

The diagnosis algorithm was programmed in a graph using Twine [7], a tool for telling non-linear stories, as Figure 1 depicts. Afterwards, was ported to a virtual environment using TweenityVR [4], a design centered methodology for rapid prototyping VR simulators. The initial graph include all the paths for a specific patient case with HF.

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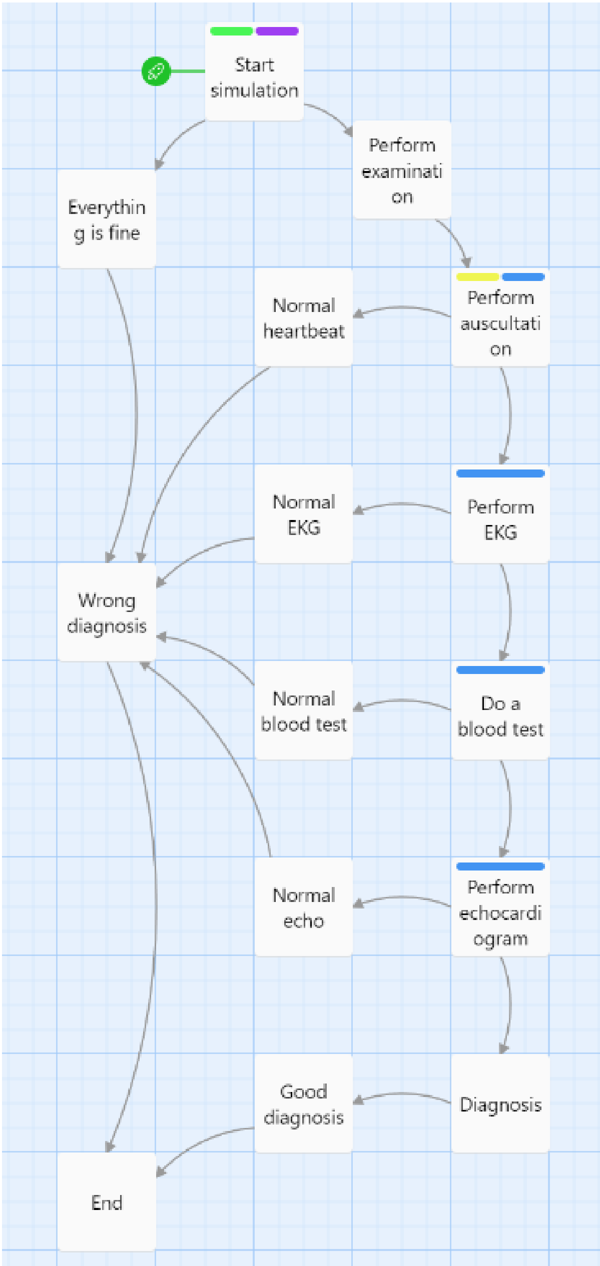

Fig. 1. Simulation graph of the story

Each node is defined by a general action followed by a description and a listing of all the specific actions required in the virtual environment. At the end, the connections to the following nodes are listed.

C. Virtual Environment

The geometry of the virtual environment (VE) was developed using a set of models designed in Autodesk Maya. Adobe Mixamo was used for modeling and rigging the virtual patient. The VE includes the doctor's office furniture, an exam room with all the necessary equipment, and a room for laboratory tests.

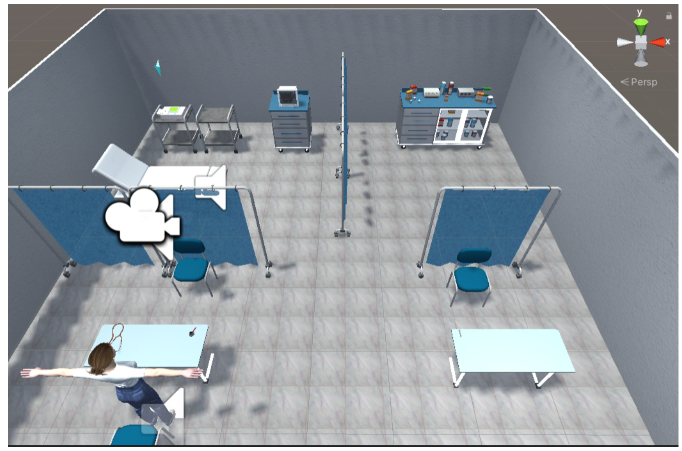

Fig. 2. Virtual environment in Unity 3D

For geometry integration with diagnosis graph, and VR programming, Unity 3D was selected due to its compatibility with TweenityVR and consumer VR headsets. Figure 2 presents the virtual environment in Unity 3D.

The interaction between the user and the virtual patient was programmed through dialog-type nodes using a dedicated geometry with the selectable options located within the VE. By means of raycasting, the user can select any option of the dialogue using a VR hand controller. Additionally, audio clips with voice recordings were used to represent the patient and the doctor, increasing the realism of the simulation.

The prototype was deployed to the Meta Quest 2 platform, a consumer standalone VR device with two hand controllers.

III. Prototype Evaluation

The preliminary evaluation of the prototype was carried out by five cardiologist experts in HF. After an explanation of the use of the prototype, each participant performed the full simulation twice and then all participated in a debriefing session where the case was reviewed. A discussion on the use of VR in cardiology simulation was also held.

On the other hand, the development team carried out an evaluation of the prototype using Nielsen 10 usability heuristics for user interface design [9]. Finding navigation using the handheld controller for teleportation confusing for new VR users. According to the *user control and freedom* heuristic, the user should have a way to easily return to certain locations while interacting with the virtual patient when accidentally teleported elsewhere.

IV. Recommendations and Future Work

A prototype of a simulator using a VR environment for heart failure diagnosis was presented. According to the experts, the prototype facilitates the learning of recommendations for the diagnosis and management of patients with HF, but it is necessary to complement it by adding additional cases. An interactive guide to patient diagnosis and management should be presented at the beginning before the simulation begins.

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Fig. 3. A user evaluating the prototype

Navigation should provide visual aids to help users navigate the VE.

As future work, experts recommend the promotion of the HF diagnosis VR simulator to help the understanding and applications of the guidelines understanding in the cardiology community.

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