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Design and Development of a Cardiac Coronary Intervention Simulator

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Abstract: This paper presents a cardiac coronary intervention simulator for training purposes. The simulator is an integrated hardware and software system. The learner uses a catheter wire to perform the desired intervention. The catheter wire movements are recorded using an embedded system. The measured values are communicated to the software that animates the catheter position inside the computer simulation. The software intervention module has two intervention options. These options are either expand the coronary or apply the stent. The animation shows the complete coronary intervention performance after selection of the desired option by the user.

Keywords: Cardiac animation, computer simulation, embedded system, graphical user interface, medical simulation.

I. INTRODUCTION

Engineers, especially electrical and electronic, design and develop solutions to ease in performing complex tasks. Simulators are low-cost, controlled environments that enable users to understand the complexities of the performance in real-world situations. This work describes the design and development of a medical simulator for the purpose of cardiac surgery training. The authors have studied the available state-of-the-art to design and develop a cardiac intervention simulator (Fig. 1) for plaque removal through coronary expansion and stent placement tasks.

The catheter movement is measured through a rotatory encoder interfaced with the Arduino UNO board. This constitute the hardware part of the simulator. This embedded system measures the length of wire. The recorded values are communicated to the software part which is coded in the Python language. The communication among both parts of the simulator is established through Universal Serial Bus.

The purpose of this coronary intervention simulator is to train the cardiac surgeons at the beginner level to use catheter wire in order to perform the tasks of plaque removal through expand coronary and applying the stent through balloon expansion. This medical simulator provides essential facilitation to the future medical experts. The development of simulator and acceptance by the domain experts as a medical simulator with basic functions shows the success of this research project.

II. BACKGROUND

In a conventional setup, coronary intervention is best understood by the novice surgeons by performing the procedure in the presence of a senior medical expert. There are higher chances of errors in performing such interventions. Advancements in engineering sciences and technology paved the way to develop low-cost training simulators to facilitate learning by the users without worrying about the adverse consequences.

There are many commercial, off-the-shelf, and state-of-the-art medical simulators are in the market that aim to simulate the interventional procedures. The Mentice VIST-G5 (Fig. 2) is a portable high-fidelity endovascular simulator. There are a number of such simulators available at the Center of Innovation for Medical Education, Aga Khan University Hospital.

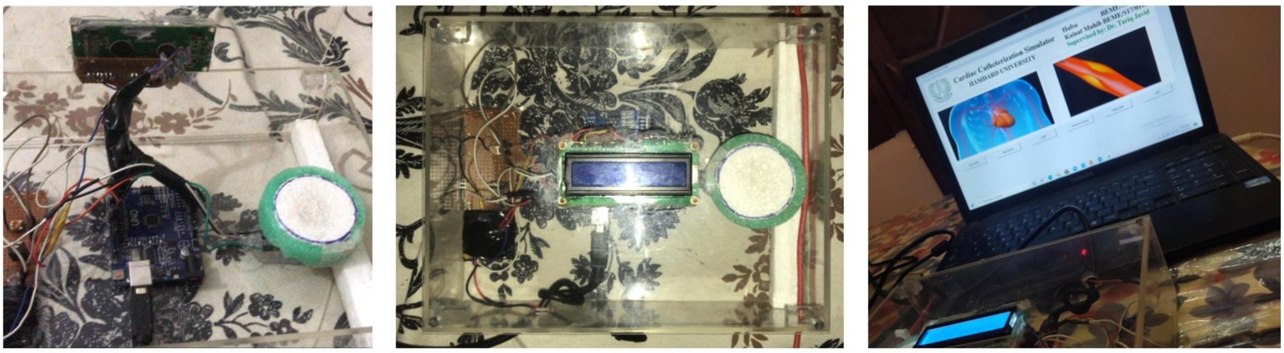

Fig. 1 The cardiac coronary intervention system. The red wire in the middle image is use as the catheter.

Fig. 2 Mentice VIST-G5 (mentice.com/vist-g5).

Ischemic heart disease caused by the narrowed heart arteries (Fig. 3) remains the leading cause of death and is responsible for 16% deaths [1]. In cardiac catheterization medical procedure, a catheter (flexible plastic tube) is inserted into a vein or artery [2]. The common uses of this medical procedure are for injecting drugs or a contrast medium for diagnosis or therapies to perform angiography, take samples, or clear blockage. The catheterization procedure is central to the therapy, diagnosis, and surgical management of numerous cardiovascular diseases.

The cardiac catheterization is among gold standards for cardiovascular diseases, especially for coronary artery disease; others are angiography and percutaneous coronary intervention (PCI) [3]. The surgical simulators are introduced to facilitate learning and mitigate many risks associated with training in a real medical procedure. Another use of such simulators is to assess the performance of medical expert at various stages of a medical procedure. Recent contributions in the literature for cardiac surgery simulators include a computer-based simulator for PCI [4], and a 3D printed patient-specific simulator for PCI [5].

The cardiac coronary intervention simulator designed and developed in this research work uses the similar pattern as used in [4], however, the actual catheter is not used to further lower the cost of the developed modality. Similarly, the models are not used. The software part in this study is designed in Python computer programming language whereas C++ is used in [4]. The 3D printing and patient-specific information are not implemented in this work as proposed in [5].

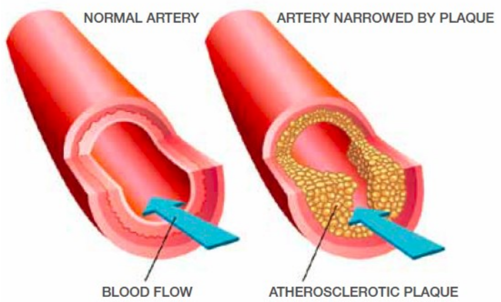

Fig. 3 Atherosclerotic cardiovascular disease [6].

III. DESIGN AND DEVELOPMENT

A. Hardware Design

The hardware design is created in Proteus (Fig. 4) and evaluated before the hardware is assembled. There are number of attempts made to discover number of ways toward a more realistic hardware design. The rotatory encoder module is then interfaced with the Arduino UNO board to measure the length of the catheter through arrangements (Fig. 1). The embedded system records the catheter length measure and send to the software part.

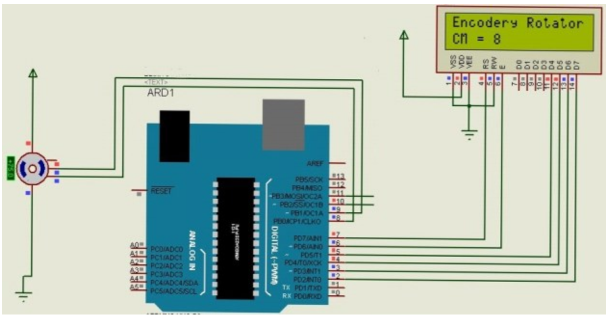

Fig. 4 The hardware model.

B. Software Development

The software development is accomplished in Python. The code is written in a Jupyter notebook. A graphical user interface (Fig. 5) is developed to receive the data from the hardware part and animate according to the options selected by the user.

Fig. 5 The graphical user interface.

IV. CORONARY INTERVENTION

The coronary intervention is explained in a flowchart (Fig. 6). Once, the simulator is ready; the catheter is inserted. It rotates the rotary encoder and the variation in the voltage potential difference is recorded. A simple computational model is used that maps the measured length to a digit sequence. This sequence of digits is transmitted to software part which show the catheter movements in the form of connected line segments. These line segments are started from the lower left corner of the graphical user interface and appeared till the desired location of artery is reached. At this point, the user stops the data and perform the coronary intervention (Fig. 7). Once, the intervention is complete, the user enables the data and pulled the catheter. The authors demonstrated these intervention at the blog site https://tariqjavid72.blogspot.com/2021/01/cardiac-catheterization-simulator-app.html.

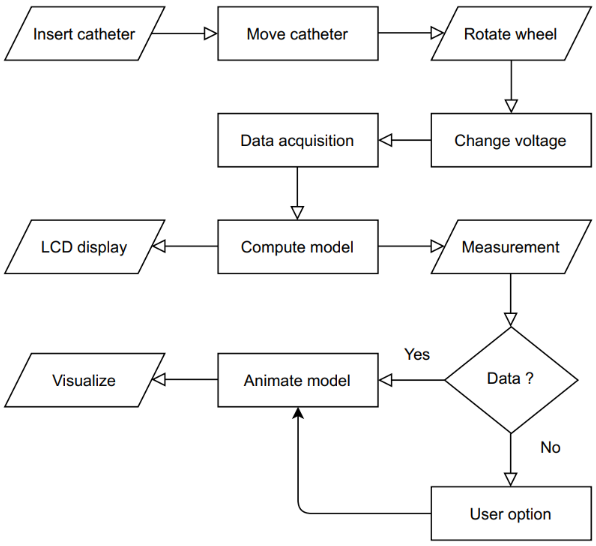

Fig. 6 Coronary intervention simulator flow diagram.

V. CONCLUSION

In this research work, a cardiac coronary intervention simulator is designed and developed to facilitate novice cardiac surgeons. The hardware design and software development is explained briefly. The simulator measures and animates the movement of catheter. The user have options to perform the expand coronary for plaque removal or to perform the task of applying stent. The demonstration results are successful and highly motivating towards a high-fidelity surgical simulator design.

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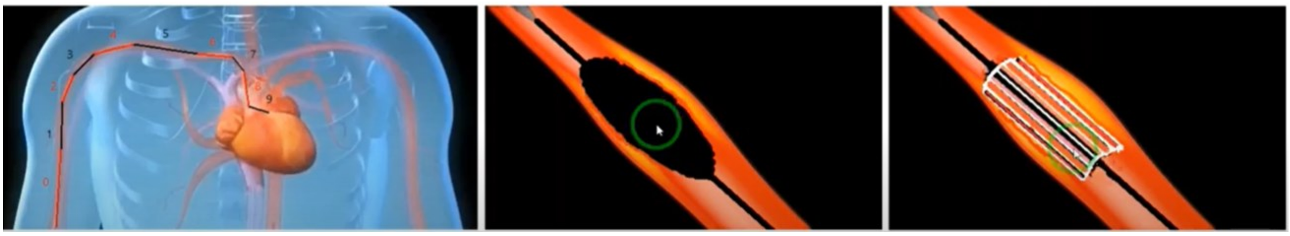

Fig. 7 (From left) Catheter reached at the desired location inside heart, expanding coronary, and applying stent.