Development of a dynamic cardiac simulator controlled by Arduino

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Aims and objectives

According to the World Health Organization, cardiovascular diseases are the leading cause of death in the world [1]. Thus, it is necessary that radiology professionals acknowledge the procedures and protocols that involve cardiac exams. Therefore, the aim of this work is to develop a dynamic cardiac simulator, which allows the training of students and professionals without the need to expose patients to ionizing radiation unnecessarily.

Methods and materials

The dynamic cardiac phantom was developed by using a cardiac simulator consisting of latex and cannulas that simulate the pulmonary and systemic circulation (Fig.1).

Fig. 1: Cardiac simulator consisting of latex.
References: Physics, Universidade Tecnológica Federal do Paraná - Curitiba/BR

The internal components are showed in the Fig. 2. The cardiac simulator has four chambers that represent two atria and two ventricles. A septum separates the chambers between right and left side. Between the atria and the ventricles are located septa that simulate the atrioventricular valves, that is, they allow the passage of fluid from the atria to the ventricles and prevent the circulation in the opposite direction.

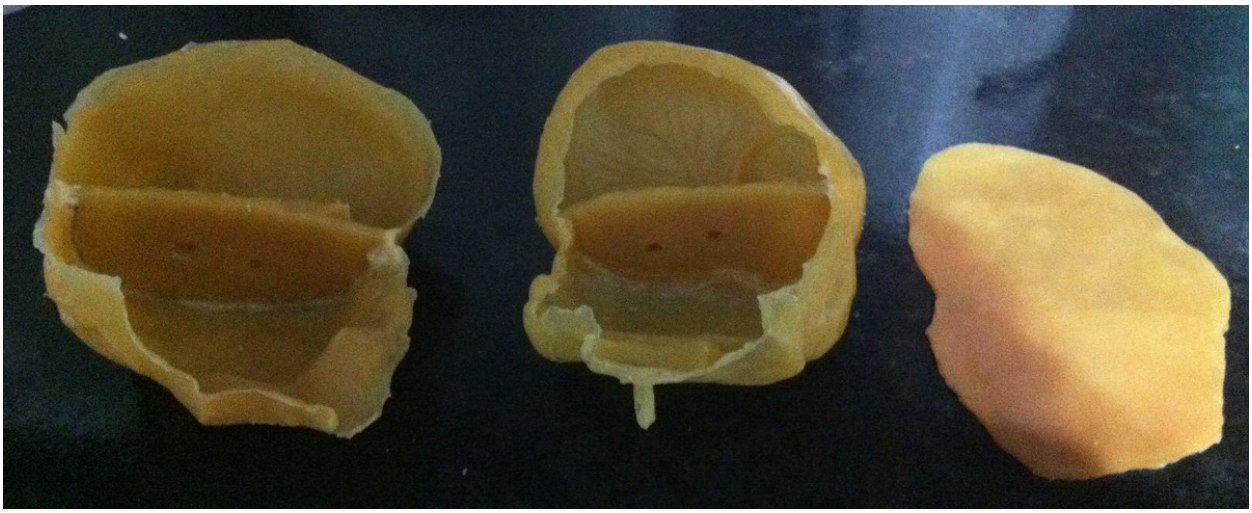

Fig. 2: Internal structures of the cardiac simulator.
References: Physics, Universidade Tecnológica Federal do Paraná - Curitiba/BR

To simulate the small circulation, a single lumen catheter was connected from the right ventricle to the left atrium and to represent the systemic circulation a double lumen catheter was connected from the left ventricle to the right atrium. One of these lumens was used to inject fluid into the right atrium.

Four hobby servomotors (Fig. 3) were positioned next to each of the four cardiac chambers of the cardiac phantom in such a way that the horns attached to each servomotor axis compress the respective chambers. The servomotors were controlled by PWM signals generated by an Arduino Uno.

Fig. 3: Hobby servomotor with horns attached to axis used to compress the phantom chambers.
References: Physics, Universidade Tecnológica Federal do Paraná - Curitiba/BR

The amplitude and frequency of rotation of the axis of each servomotor was controlled from a code developed in the Arduino Integrated Development Environment. For each heartbeat the total rotation range is 90 degrees, being 45 degrees clockwise and 45 degrees counterclockwise, and the time for 1 degree rotation is 10 milliseconds. Movement occurs synchronously.

Results

The phantom developed in this work (Fig. 4) resembles dynamic phantoms presented in the literature [2,3] that reproduce the heart rate during the simulation of radiological procedures. A differential of the presented simulator is the possibility of changing the rotation time of the servomotor horns in the developed code, which allows simulating pathologies such as cardiac arrhythmias.

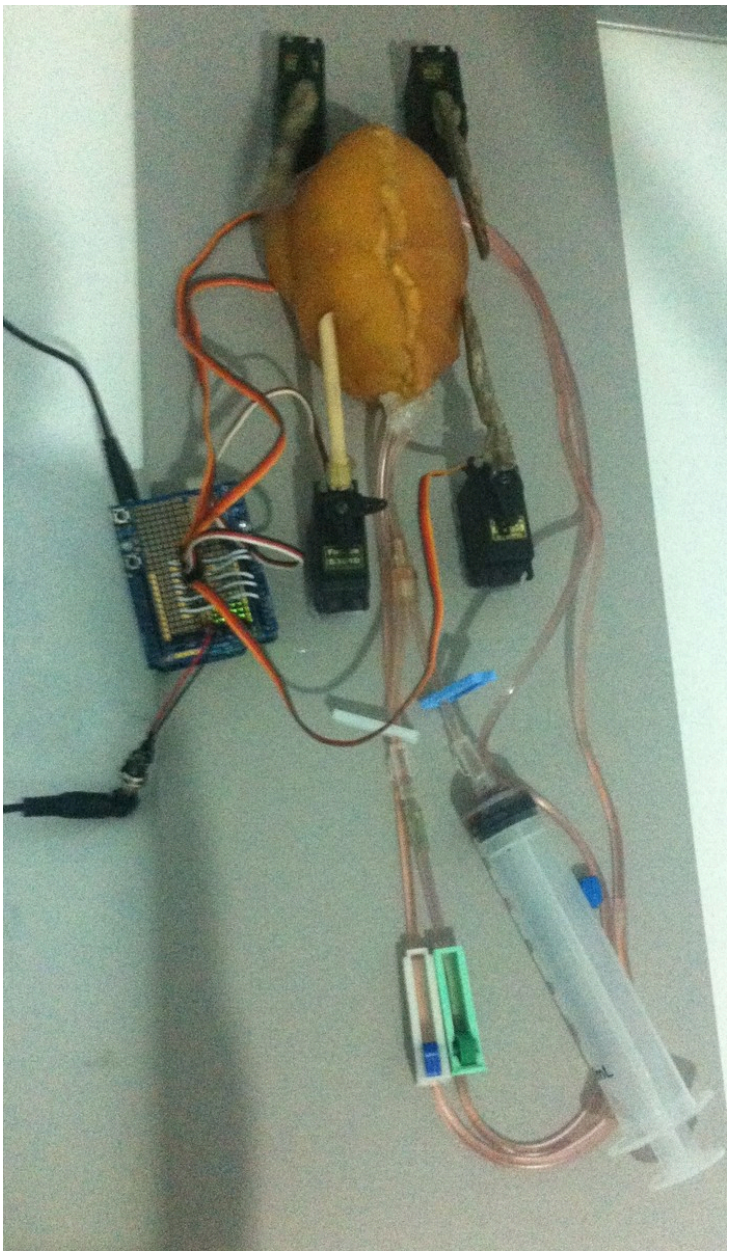

Fig. 4: Developed cardiac phantom. The four hobby servomotors next to each chamber and the syringe used to inject fluid test and iodine-based contrast.
References: Physics, Universidade Tecnológica Federal do Paraná - Curitiba/BR

A radiographic image (Fig. 5) shows the internal components of the phantom. The image showed in the Fig. 6 was recorded in a fluoroscopy equipment and indicated that injected iodine-based contrast filled the cardiac chambers.

Fig. 5: Radiographic image showing the internal components of the cardiac simulator and the catheters that connect the chambers.
References: Physics, Universidade Tecnológica Federal do Paraná - Curitiba/BR

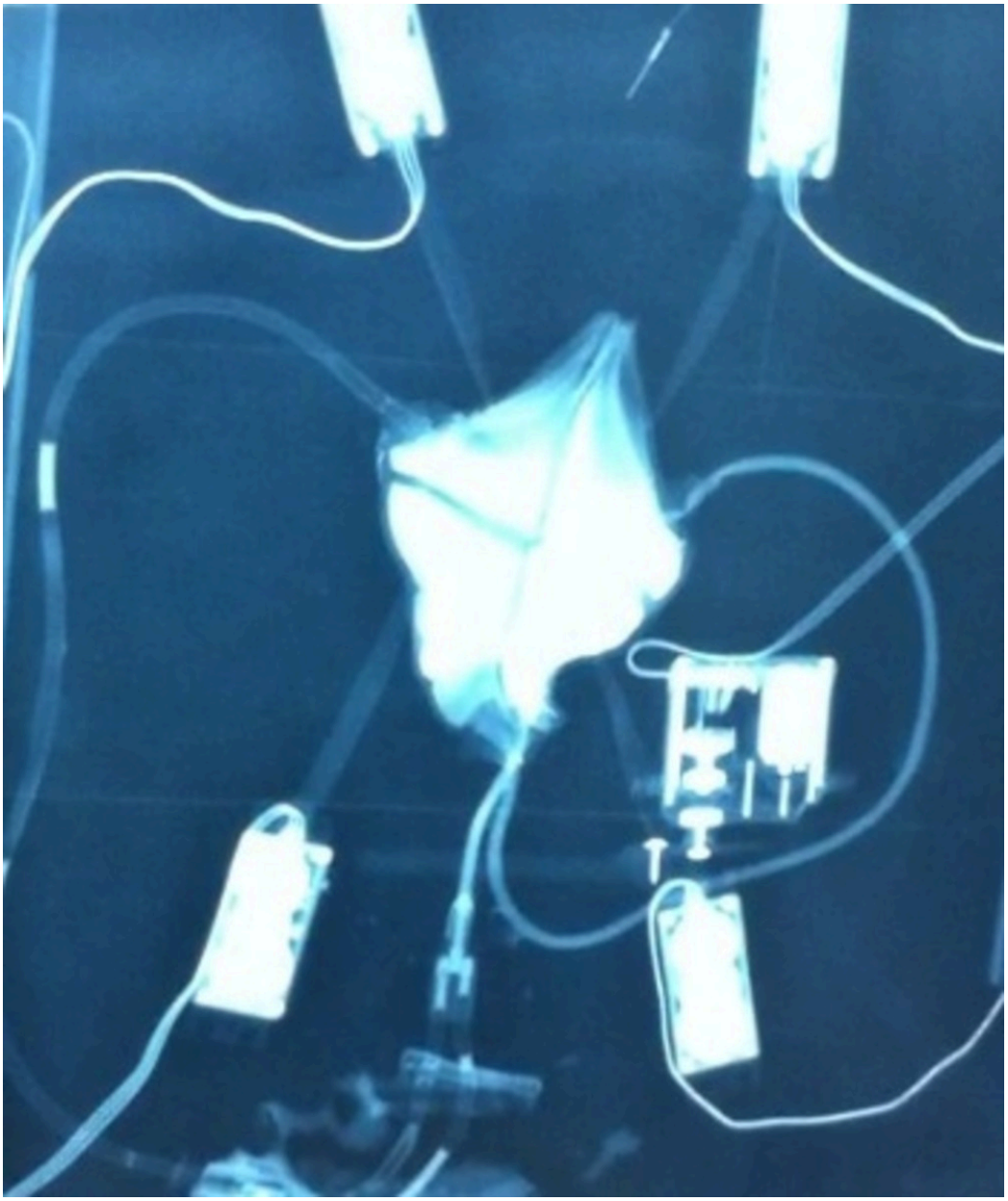

Fig. 6: Fluoroscopy image showing the cardiac chambers filled with iodine-based contrast.
References: Physics, Universidade Tecnológica Federal do Paraná - Curitiba/BR

The Arduino code developed allowed controlling the movement of the horns of each servomotor independently. The compression of the atriums and ventricles occurred at a frequency of 1 hertz. However, the intensity of compression of the cardiac chambers was not enough to completely drain them out, which resulted in low flow velocity. There was also a small fluid return through the cannulas that connect the ventricles to the atrium.

Conclusion

The developed simulator allows independent control of the compression of each chamber of the cardiac phantom. This can contribute to professional training through simulation, making it possible to prepare students for different situations that can be experienced in practice, as well as to improve protocols to reduce doses of radiation and errors in procedures.

Improvements are being made to prevent fluid reflux and also to vary the heart rate frequency to simulate atrial and ventricular arrhythmias.

References

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