Developing a C-Arm X-ray simulator for medical training without exposure to X-ray radiation

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Introduction

A C-Arm X-ray machine is a medical imaging modality used during surgical and diagnostic procedures for real-time fluoroscopy[1]. A C-shaped arm allows the rotation of the radiation source and detector around the patient. It captures multiple angles to create high-resolution and real-time images of anatomical structures [1, 2]. The X-ray generator sends beams of radiation through the patient, which the detector will convert into visible images on the monitor display (*Figure 1*) [1].

Advantages of a Simulator in Medical Training:
X-ray radiation can also cause damage to molecular structures and potentially increase the risk for adverse effects such as skin burns, hair loss, and increased cancer over time [3,4] . Simulators allow a safe, radiation-free environment in which medical professionals can practice X-ray-guided procedures such as those performed with C-Arm machines [5] . This may further create avenues for medical trainees to perform complex procedures without exposing themselves or others to radiation [5] .

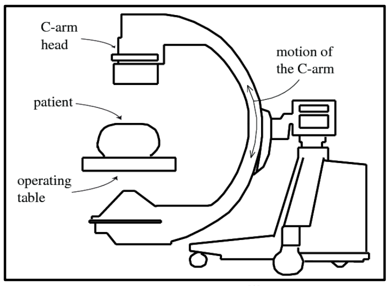

Figure 1: A typical C-arm Setup [6]

Materials and Methods

Design and Prototyping
The research process began by carefully analysing what was currently designed in the X-Ray C-Arm simulator, focusing on what can be improved. In CAD, the design work was performed in Fusion 360, where several generations of different components on the simulator were developed. This was followed by prototyping: several generations were laser-cut and 3D-printed to make and test the various parts to ensure the new design would be more compact and efficient. Multiple serious of testing and continuous adjustments were made in the process to obtaining the second version of the prototype.

Mechanical, Electrical, and Software Integration
The next step in development was the refinement of the mechanical and electrical aspects of the simulator. A more powerful stepper motor was fitted, and the structure was reworked for increased stability and structural rigidity. The electrical system was then rewired, incorporating longer, colour-coded cables to organise the wires and avoid the wires becoming tangled. Finally, the Arduino code was revised and improved to eliminate internally generated vibrations that ensured smoothness in the operation of motors. The code was also revised to use one joystick to control both motors. Regular troubleshooting was conducted to handle the different challenges and further enhance the performance of the simulator.

Category	Material/Component
Software	Autodesk Fusion 360
	Ultimaker Cura
	Arduino IDE
Hardware	Stepper Motor(Nema 17, Nema 23)
	Acrylic Plates (Thicker)
	Bearings and Gears
	Jumper Cables (Longer, Color-coded)
	Arduino Mega
	Stepper Motor Drivers
	Joystick
Prototyping Tools	Laser Cutting Machine
	Creality Ender 3 - Max Neo 3D Printer
	Soldering Kit
Safety Equipment	Protective Gear

Table 1: Materials used to make the C-Arm Simulator

Results

Design Optimisation:
The volume of the rotating component was reduced by 62.8%, making it more portable and efficient. The initial housing size of 200mm x 100mm x 65mm was reduced to 120mm x 66mm x 61mm by optimising motor placement and reducing wasted space.

Mechanical Enhancements:
Improved Stability: The simulator's rotating module was upgraded with a more powerful stepper motor (NEMA 23 from NEMA 17), increasing speed and operational stability.
Increased Durability: Thicker acrylic plates (8mm vs 5mm), Thicker Shaft (5mm vs 10mm diameter), Larger bearings (10mm vs 18mm) were used to reinforce the structural strength of the simulator.

Electrical System Improvements:
Longer colour coded wires were used as the previous prototype had tangled wires which made troubleshooting and changes to the wiring very challenging .

Code Refinement:
Reduced Vibrations: Internal vibrations were minimised by refining the Arduino motor control code, including the implementation of a while loop, resulting in smoother motor operation and more precise C-Arm control.
Simplified Interface: The number of motors controlled by joysticks was reduced from two to one, creating a more user-friendly interface.

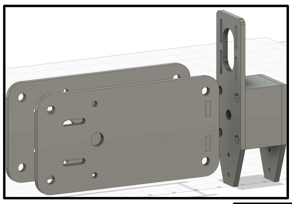

Figure 2 : Previous CAD model of rotating component of C-arm simulator with dimensions 200mm x 100mm x 65mm.

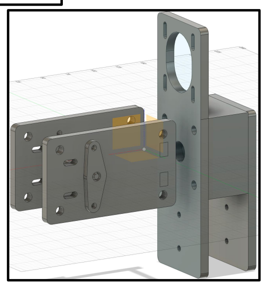

Figure 3 : New CAD model of rotating component of C-arm simulator with dimensions 120mm x 66mm x 61mm providing a 62.8% reduction in volume

Conclusion

The project successfully enhanced the X-Ray C-Arm simulator in design, functionality, and stability. A reduction in the size of the housing by 62.8% made it compact for application within a teaching environment. The mechanical upgrades increased its durability and improved motor performance, while code refinements significantly reduced the level of vibrations to result in smoother operations. This prototype of the unit could be further developed with the capabilities of an Arduino shield, which can provide permanent electrical connections. Secondly, an application could be developed that would drive the C-Arm and enable wireless control while having some presets for commonly used viewing angles in X-ray imaging.

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