PROJECT

REPORT ON

DESIGN OF C-ARM ROBOT FOR SCANNING APPLICATION

Submitted to

NMAM INSTITUTE OF TECHNOLOGY, NITTE

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In partial fulfillment of the requirements for the award of the

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by

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1. Introduction:

A C-arm robot is a mechanical system designed to position and orient an attached end-effector or imaging device in three-dimensional space with high precision. The name C-arm comes from the C-shaped frame often used in medical and industrial systems, which provides wide angular coverage around an object while keeping the structure compact. In this project, a 3 Degrees-of-Freedom configuration is implemented to achieve essential motions, typically one rotational and two translational axes sufficient for tasks such as inspection, imaging, or positioning in constrained environments.

Robotic manipulators with limited but well-chosen DOF offer advantages of lower cost, reduced complexity, and improved reliability while still covering the workspace required for specific applications. A 3-DOF C-arm can be applied in fields such as non-destructive testing, medical imaging, object scanning, and laboratory automation, where full 6-DOF motion is not necessary.

This work aims to design, model, and prototype a 3-DOF C-arm robot capable of smooth, repeatable motion along its axes while maintaining structural rigidity and precise positioning. Key considerations include kinematic design, actuator selection, load-bearing capacity, control strategies, and workspace optimization. The introduction of this system serves as a foundation for further development into more advanced robotic platforms, offering a balance between mechanical simplicity and functional versatility.

2. Purpose and use of the project:

The C-arm robot is designed to take X-ray images from different angles during surgeries and medical procedures, helping doctors see inside the body without making large cuts. It can move around the patient to capture a series of images and then use a special computer program (image stitching) to join these images together, so doctors get one big, clear picture.

2.1 Purpose of C-arm Robot

- Makes it easier for doctors to see inside the body during operations
- Takes multiple X-ray pictures from different positions
- Joins (stitches) all the pictures into one big image for better diagnosis
- Helps surgeons do procedures more safely and accurately
- Reduces the need for opening up the body (minimally invasive)

2.2 Applications of C-arm Robot

- Used in fixing broken bones (orthopedic surgery)
- Helps with heart and blood vessel surgeries
- Used during kidney stone removal or other urology procedures
- Useful in brain and spine surgeries
- Saves time in emergency cases by providing quick imaging.

3. Objective:

The main objective of this project is to design, develop, and prototype a 3-Degree-of-Freedom (3-DOF) C-Arm robotic system capable of performing precise linear and rotary movements required for scanning and imaging applications. The system aims to capture multiple images from different angles around an object and combine them into a single, comprehensive image through image stitching techniques.

The robot is intended to replicate the motion and functionality of medical C-Arm imaging systems used during surgeries and diagnostic procedures. The design focuses on achieving smooth, repeatable motion, structural stability, and accurate positioning while maintaining mechanical simplicity.

3.1 The specific goals include:

- Designing a compact and efficient robotic mechanism with one linear and two rotary joints.
- Implementing kinematic modeling and motion control algorithms to achieve precise and synchronized movement.
- Developing a control system using a microcontroller (such as Raspberry Pi) for automated scanning.
- Ensuring accurate calibration, safety limits, and reliability during operation.
- Demonstrating the robot’s ability to simulate imaging tasks by capturing and stitching data for a complete scan view.

Ultimately, the project aims to create a functional C-Arm robot prototype that provides a foundation for advanced robotic imaging systems, contributing to improved diagnostic accuracy and surgical assistance.

4. Methodology:

The project is carried out in into following parts:

4.1Requirement Analysis

- The first step was to clearly define what the system needed to achieve. Since the project focuses on creating a scanning application with imaging simulation, the arm was required to perform two basic motions: rotation around an object and linear translation.
- These requirements shaped all design decisions that followed.

4.2 System Planning

- Once the requirements were clear, we then move to planning the system architecture. The control platform was shortlisted between Arduino and Raspberry Pi, keeping in mind ease of programming and compatibility with motion control libraries.
- For actuation, stepper motors and servo motors were considered to handle the two distinct motions, precise angular rotation and linear displacement.

4.3 Control Algorithm Development

- The control logic was then developed to translate user commands into physical motion.
- Kinematic equations are used to model movement, ensuring predictable and repeatable positioning.
- User inputs such as angle and step size will be then mapped directly into motor instructions, forming the core of the motion-planning algorithm.

4.4 Prototype Development

- With the plan and algorithm in place, a working prototype needs to be built.
- A C-Arm style structure was assembled using available mechanical components. This provided a stable yet flexible base to integrate motors, controllers, and sensors.
- The prototype allowed iterative testing and refinement before moving toward full validation.

4.5 Safety and Testing

- To ensure safe operation, motion limits are defined in both rotation and translation to prevent collisions or overextension of the arm.
- The system then needs to be tested under multiple scanning scenarios, varying speed, step size, and object positioning.
- This phase will then highlight potential risks and confirm that the control system responded reliably under different conditions.

4.6 Calibration and Optimization

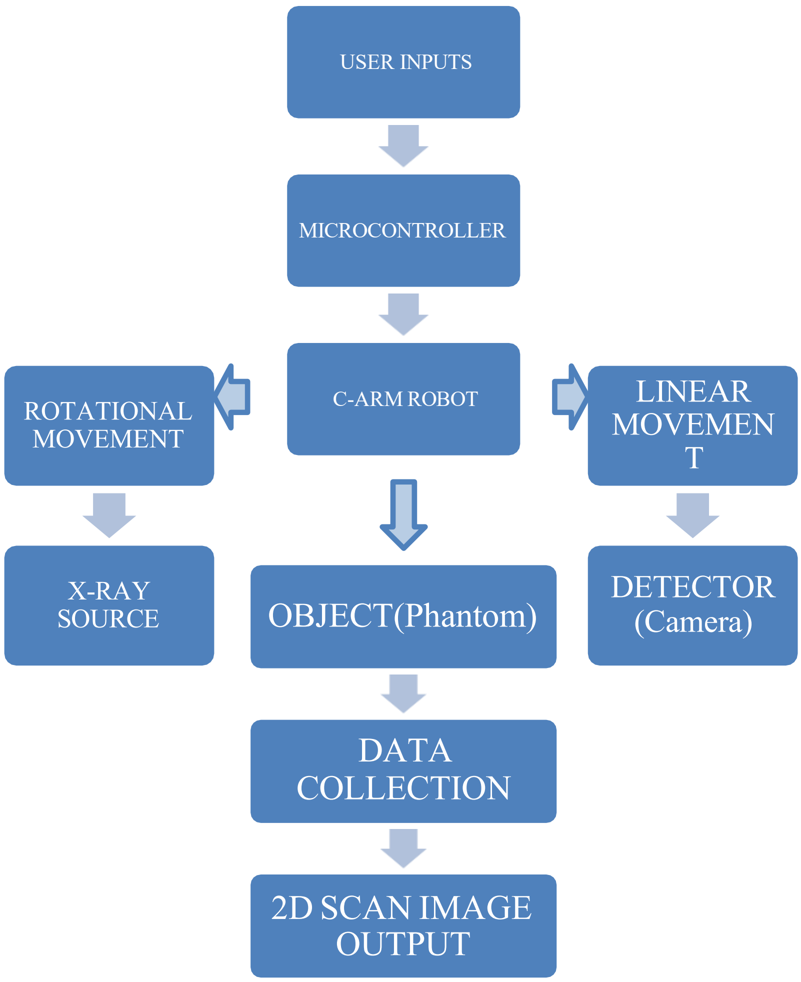
- Calibration focused on aligning commanded values (angles, linear steps) with actual physical motion.
- Fine-tuning will then be carried out until the arm consistently produces accurate results. Optimization efforts further reduced error margins and improved smoothness of movement.

4.7 Data Acquisition and Processing

- Once the motion system is stable, data acquisition will be integrated. Readings will be stored either on the microcontroller itself or transmitted to a connected PC.
- This data stream formed the basis for analyzing system performance.

4.8 Image Formation and Validation

- The final step is to validate whether the system could generate scan patterns that matched the expected simulation outputs.
- The captured data will then be compared against reference patterns, confirming whether the mechanical and control subsystems worked together as intended.
- Successful validation will show that the prototype could reliably reproduce the scanning motion required for imaging applications.



5. Working of C-ARM Robot:

- The user inputs the scan parameters like how many angles to scan and step size.
- The microcontroller (Raspberry Pi) calculates the movement needed using kinematic equations.

5.1 The robot moves the C-Arm structure in two ways:

- Rotational Movement goes around the object to scan from different angles.
- Linear Movement goes along the arm to cover different sections of the object.

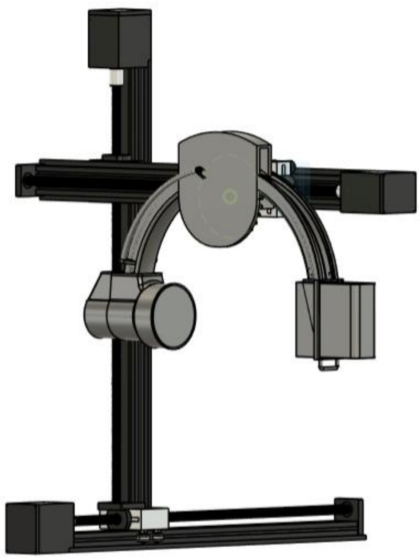
5.2 At each step:

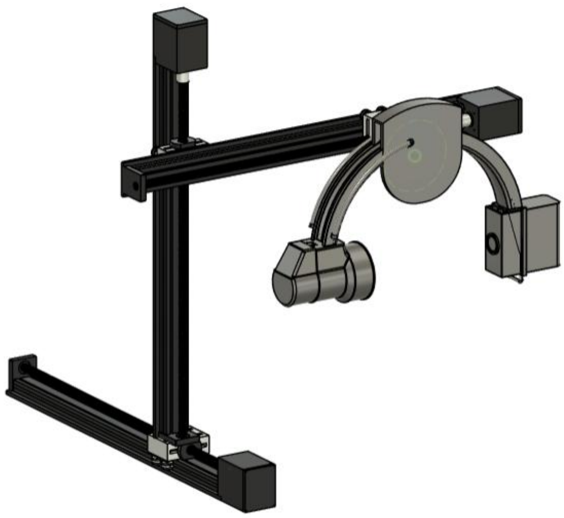
- The simulated X-ray source shines light through the object.
- The simulated detector records the light intensity.
- The data collected at different positions is stored.
- Finally, a simple 2D image is created by combining all the recorded data, showing a projection of the object.

6. Mechanism:

The C-Arm robot operates with a three-joint mechanism for precise and flexible medical imaging. The first joint is linear, moving the entire arm forward and backward to position the imaging system relative to the patient. The second joint is rotary, tilting the imaging device to align accurately with the targeted anatomical area. The third joint is rotary, rotating the arm around the patient to provide multi-angle views without repositioning them. Together, these joints enable real-time, accurate imaging, enhancing diagnostics and surgical procedures while maintaining patient comfort and operational flexibility.

- Joint 1 Linear: Moves C-Arm forward/backward for positioning
- Joint 2 Rotary: Tilts device for alignment with body sections
- Joint 3 Rotary: Rotates arm around patient for multi-angle views
- Provides precise, flexible, and real-time imaging
- Supports accurate 3D modeling and surgical assistance





7. Forward and Inverse Mechanism:

D-H Parameters:

Links	Theta	D	A	Alpha
1	0	d2	0	90
2	0	d3	0	-90
3	Theta3+90	Z	0	90
4	Theta4	0	a4	0

$$\text{i-1Ti} = \begin{bmatrix} C\theta i & -S\theta iC\alpha i & S\theta iS\alpha i & aiC\theta \\ S\theta i & C\theta iC\alpha i & -C\theta iS\alpha i & aiS\theta \\ 0 & S\alpha i & C\alpha i & di \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Link 1: θ1=0, d1=d2, a1=0, *α1=90*°

$$\text{0T1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & d2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Link 2: θ2=0, d2=d3, a2=0, *α2=-90*°

$$\text{1T2} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & d3 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Link 3: θ3=θ3+90, d3=0, a3=0 *α3=90*°

$$2T3 = \begin{bmatrix} C(\theta3+90) & 0 & S(\theta3+90) & 0 \\ S(\theta3+90) & 0 & -C(\theta3+90) & 0 \\ 0 & 1 & 0 & d2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Link 4: θ4=θ4, d4=0, a4=a4, *α4*=0°

$$3T4 = \begin{bmatrix} C\theta4 & -S\theta4 & 0 & a4C\theta4 \\ S\theta4 & C\theta4 & 0 & a4S\theta4 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

0T4=0T1*1T2*2T3*3T4

$$0T4 = \begin{bmatrix} -S(\theta3)C(\theta4) & S(\theta3)S(\theta4) & C\theta3 & -a4S(\theta3)C(\theta4) \\ C(\theta3)C(\theta4) & -S(\theta3)C(\theta4) & S\theta3 & a4C(\theta3)C(\theta4)-d3 \\ S\theta4 & C\theta4 & 0 & a4S(\theta4)+d2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$J^{+} = J^{\mathrm{T}}(JJ^{\mathrm{T}})^{-1}$$

8. References:

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