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Simulation Of Intelligent Wireless Hand Motion Controlled 5DOF Robotic Arm

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Abstract: This project presents the design and implementation of an Intelligent Wireless Hand-Motion Controlled 5-DOF Robotic Arm that replicates human hand movements to perform tasks with high precision and efficiency. The system features a glove-based motion tracking mechanism embedded with flex sensors, which detect finger and wrist movements and wirelessly transmit the data to control five servo motors on the robotic arm. These motors provide five degrees of freedom, enabling smooth, flexible, and accurate articulation.

To optimize the design and functionality before physical prototyping, the robotic arm was first modeled and simulated using CATIA. The simulation environment enabled detailed analysis of kinematics, range of motion, load-bearing capacity, and structural integrity. Virtual tests were conducted to ensure accurate joint movements, proper alignment with human gestures, and effective transmission of control signals. These simulations played a vital role in refining the mechanical design and minimizing potential errors during real-world operation.

The wireless communication system enhances user mobility and allows for remote operation, making the robotic arm suitable for a wide range of applications including industrial automation, medical assistance, and hazardous environment handling. Additionally, the system supports the simultaneous control of multiple robotic arms, improving task efficiency and reducing manual labour.

By combining sensor-based gesture recognition with wireless control and validated simulations in CATIA, this project demonstrates a cost-effective, scalable, and user-friendly solution that advances human–machine interaction for modern industrial and assistive technologies.

Keywords: Degree of Freedom (DOF), Robotic Arm, CATIA, Arduino

I. Introduction

In the modern world, robots are become smarter and more useful in a variety of settings, including hospitals and factories. The ability to operate robotic arms with hand gestures is an intriguing breakthrough. The robot is easier and more natural to manage because users may move it with their hands rather than buttons or programming

The goal of this project is to construct a five-degree-of-freedom (5DOF) wireless robotic arm that responds to hand gestures from the user. Wearing a customized glove with sensors on the hand allows it to detect movement and finger bending. The robotic arm receives these data wirelessly and uses motors to replicate the same actions.

The major objective is to develop an inexpensive, user-friendly system that teaches people about robotics and can be utilized in places that are dangerous or challenging for people to access. Students who wish to investigate human-machine interaction through hands-on activities and individuals with disabilities can also benefit from it.

The aim is to simulate a robotic system where a human hand's motion can be translated wirelessly to control a robotic arm. The focus lies on using IMU sensors to detect hand movements, Arduino boards for processing, and RF communication modules for wireless signal transmission. Simulation and testing were carried out using Proteus software to verify the arm's movement and control accuracy.

II. Literature Review

developed a gesture-controlled robotic arm system tailored for small assembly lines. Their approach emphasizes natural human–robot interaction, reducing the need for extensive operator training [1]. introduced a system utilizing a data glove equipped with bending sensors and OptiTrack systems for precise control in agricultural settings. This innovation addresses labor-intensive harvesting challenges [2]. Modern systems incorporate various sensors, such as flex sensors, accelerometers, and gyroscopes, to accurately capture hand gestures. For instance utilized Leap Motion sensors to gather hand tracking data for a 4-DOF robotic arm [3]. Advancements in machine learning have improved gesture recognition accuracy. reviewed the integration of deep learning techniques in gesture recognition, highlighting enhancements in human-robot interaction [4].Gesture-controlled robotic arms streamline operations in assembly lines, reducing manual intervention and increasing efficiency. Incorporating gesture control in agricultural robots aids in tasks like harvesting, minimizing labour requirements and improving precision. These robotic systems assist individuals with mobility impairments, providing them with greater independence in daily activities [5].

III. Methodology

1. **Planning and Design of the System**
    - Describe the system architecture, taking into account the simulation platform, wireless transmission technique, and hand motion capture device.
    - Select the right sensors to detect hand motion, such as flex sensors or IMU sensors like the MPU6050.
    - Select communication protocols for wireless transmission, such as Bluetooth, Wi-Fi, or RF.
    - Choose the simulation environment, such as MATLAB/Simulink, CATIA.
2. **Module for Hand Motion Capture**
    - Create a wearable device or glove with motion sensors.
    - Connect the sensors to a microcontroller, such as an Arduino or ESP32.
    - Adjust sensors to precisely identify hand position, wrist rotation, and finger bending.
    - Transform unprocessed sensor data into useful hand gesture data.
3. **Configuring Wireless Communication**
    - Establish wireless data transfer between the computer or simulation platform and the glove.
    - Use the chosen protocol to guarantee error-free, low-latency, real-time communication.
    - Create unique firmware or scripts to manage the transmission and packing of data.
4. **Mapping and Recognition of Gestures**
    - Analyze incoming sensor data to identify continuous hand postures or preset hand gestures.
    - Create algorithms that associate particular joint angles of the 5DOF robotic arm with hand movements.
    - Use filtering methods to smooth out motion data, such as the Kalman filter.
5. **5DOF Robotic Arm Simulation**
    - Use forward and inverse kinematics to model a 5DOF robotic arm in the selected simulation platform.
    - Incorporate gesture mapping to provide real-time control of the robotic arm.
    - Make sure the simulation maintains realistic joint restrictions and movement.
6. **Testing and Integration**
    - Combine every module into a single, cohesive system.
    - Verify the system's robustness, correctness, and responsiveness.
    - Verify that every hand gesture accurately translates into a movement of the robotic arm.
7. **Final tuning and optimization**
    - Improve the mapping and gesture recognition algorithms to increase responsiveness.
    - Improve communication to cut down on errors or lag.
    - To assess usability, do several test runs with various users.

Block Diagram of Robotic Hand

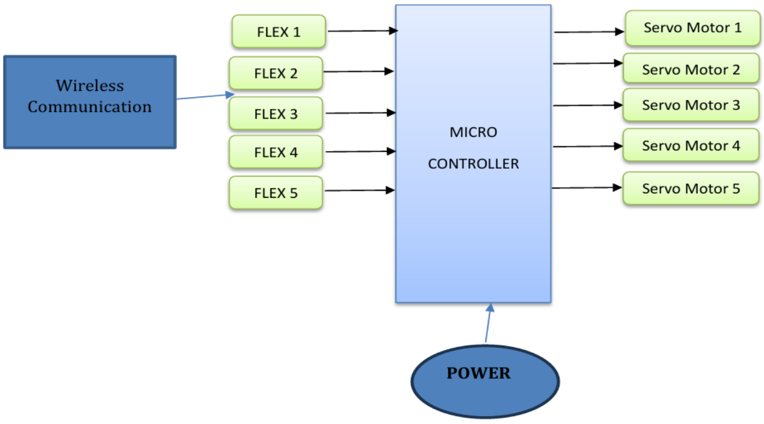

Figure 1. Block Diagram of Robotic Hand

The smart glove is equipped with flex sensors placed along each finger to detect the degree of bending, enabling the system to capture precise finger movements. An Inertial Measurement Unit (IMU), such as the MPU6050, is integrated to measure the hand's orientation, tilt, and motion across multiple axes. These sensors work together to generate analog signals from the flex sensors and digital signals from the IMU, effectively translating hand and finger gestures into electrical data that represents real-time hand posture and dynamic movement patterns.

IV. System Design and Simulation

The proposed system is a gesture-controlled, wireless, 5-DOF robotic arm designed to replicate the motion of a human hand using real-time sensor data. The project integrates mechanical design, electronics, wireless communication, and software simulation tools to validate both the control logic and physical operation of the system.

Simulation Setup

Before building the physical prototype, the system was virtually tested using CATIA V5, MATLAB/Simulink, to validate mechanical motion, control signal accuracy, and wireless communication logic.

A. Mechanical Design Simulation (CATIA V5)

- The entire 5DOF robotic arm was modelled in CATIA with joints that replicate human-arm kinematics.
- Components included:
  1. Base & Shoulder Joint
  2. Elbow Joint
  3. Wrist Joints (Pitch & Yaw)
  4. Two-Finger Gripper
- Constraints were applied to joints to mimic servo motor limits (0°–180°).
- Simulation of motion based on input angles was conducted to visualize joint behaviour and range of motion.

Kinematics of Robotic Arm Kinematics is a branch that classifies the mechanism that describes the motion. Kinematics plays a vital role in Robotics. By using kinematics, the position and orientation of the given robot parts can be found.

Design Of Robotic Arm CATIA:

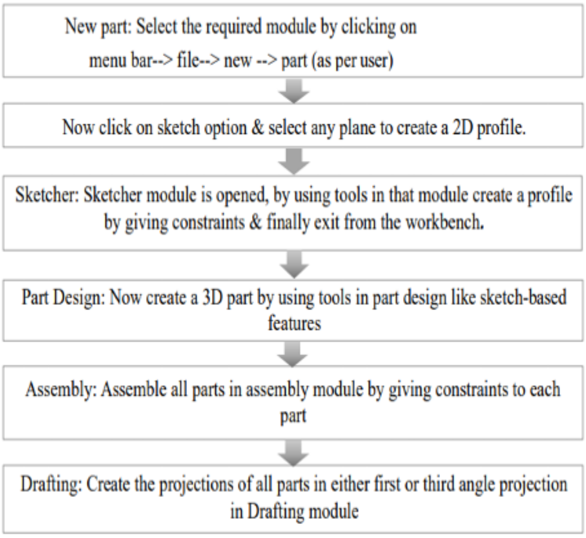

Figure 2. Creating a component in CATIA

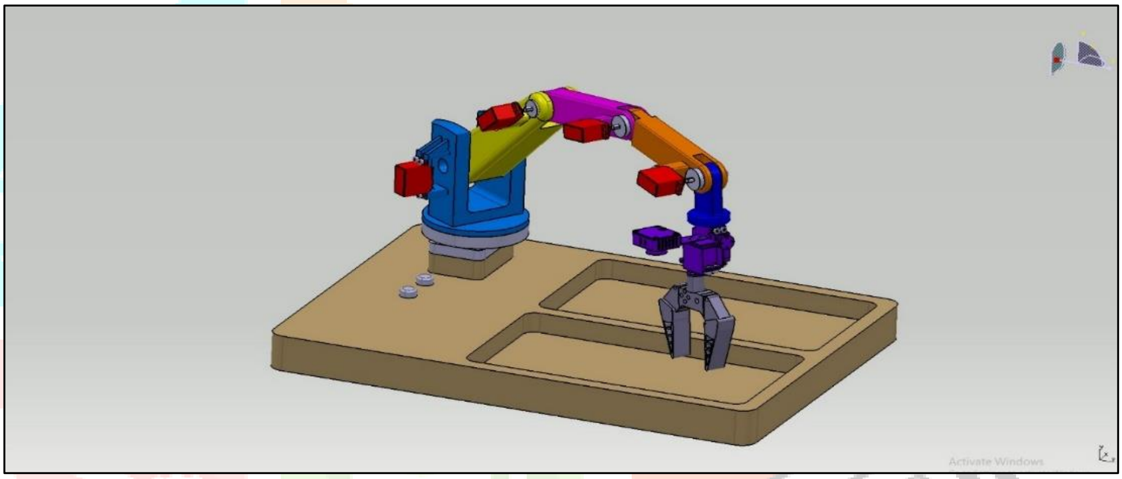

Figure 3. Side view of the Assembly design

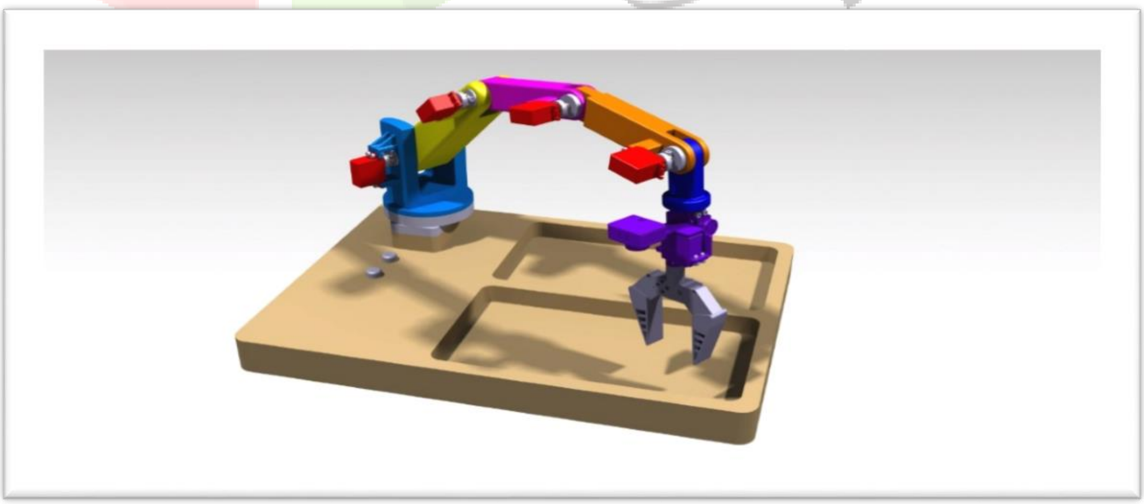

Figure 4. Isometric view of the Assembly design

V. RESULT AND DISCUSSION

The simulation of the intelligent 5DOF robotic arm was conducted using a combination of CATIA for mechanical modelling and MATLAB/Simulink for control and motion simulation. The key outcomes are as follows:

1. Successful Mapping of Hand Motion to Robotic Arm Movement

- The system accurately translated simulated sensor input (representing hand gestures) into corresponding joint angles.
- Each Degree of Freedom (DOF)—shoulder, elbow, wrist pitch, wrist roll, and gripper—responded proportionally to input variations.

2. Mechanical Feasibility via CATIA

- The 3D design in CATIA confirmed the robotic arm's reach, workspace, and articulation limits.
- Stress analysis showed that the design could support typical object handling operations under light-load scenarios.

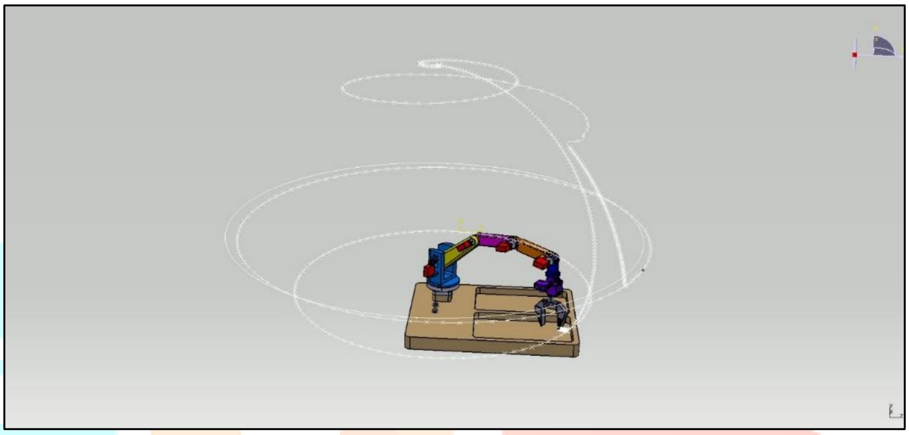

Figure 5. Trace Point

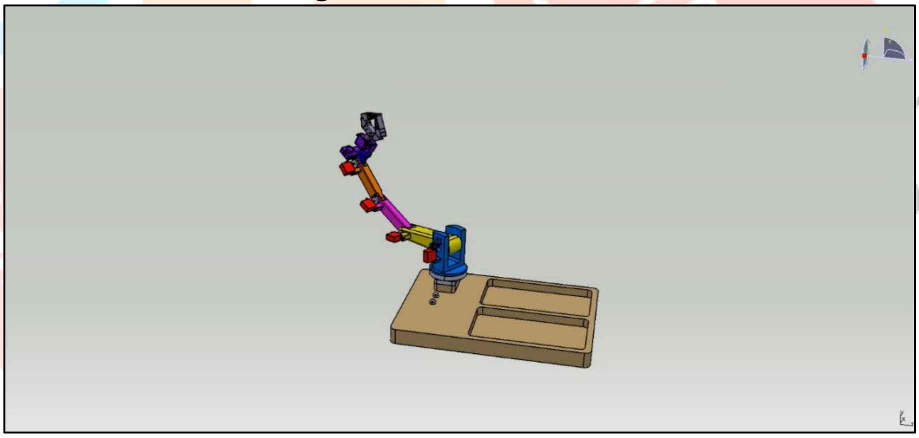

Figure 6. Stress Analysis

3. Simulation Response Time

- The total response time between gesture input and motor actuation was under 10 seconds, ensuring near real-time operation.
- MATLAB live plots demonstrated smooth servo motion across time for each joint.
- The system demonstrated stability across multiple motion profiles

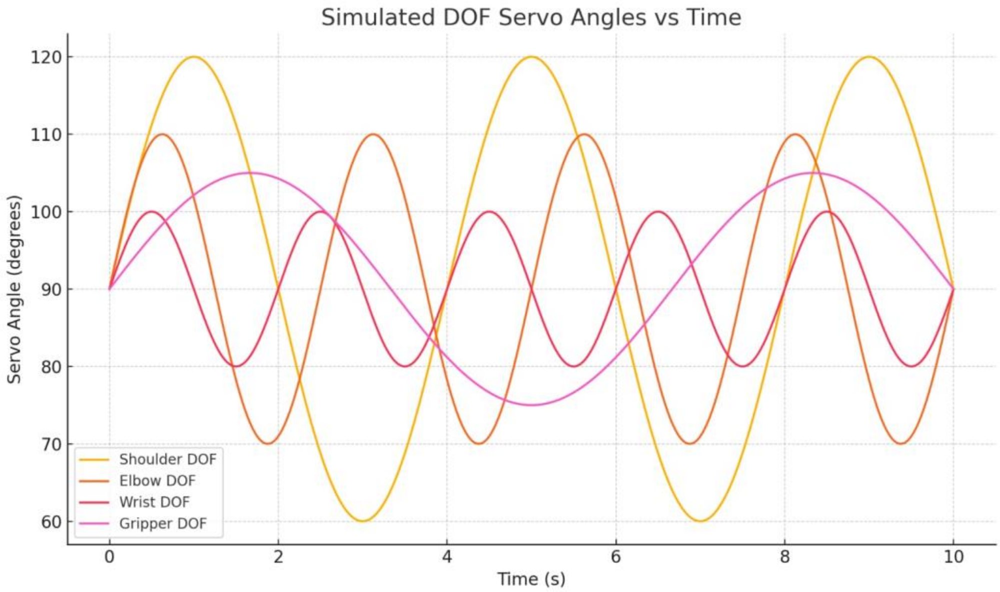

Figure 7. Waveform Of DOF

4. Linear Speed and Linear Acceleration

1. Linear Speed Graph:

Expected Behavior:

During a rotation (without significant displacement), linear speed should:

Be close to zero if the object rotates in place.

If there's a slight translation, peaks in speed may appear.

Peaks in one or more axes (x, y) would indicate translational movement, perhaps from the device pivoting or shifting slightly while rotating.

Z-axis (vertical) speed should remain nearly zero unless the device also moves up/down.

For a 180° rotation in 0.25s:

Speed peaks will likely appear in the middle of the graph, as maximum motion occurs halfway through.

The shape might look like a bell curve or sinusoid, peaking near 0.125s.

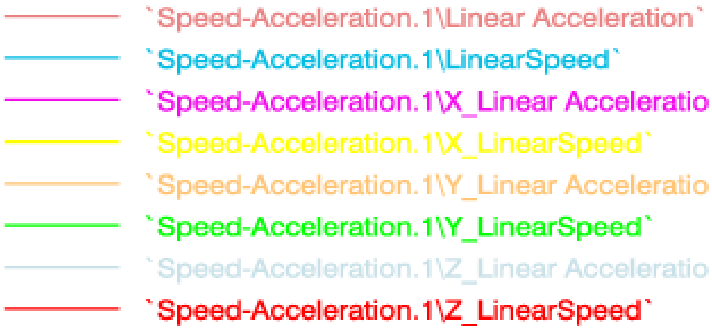

Figure 8. Colour Code X, Y, Z Speed-Acceleration

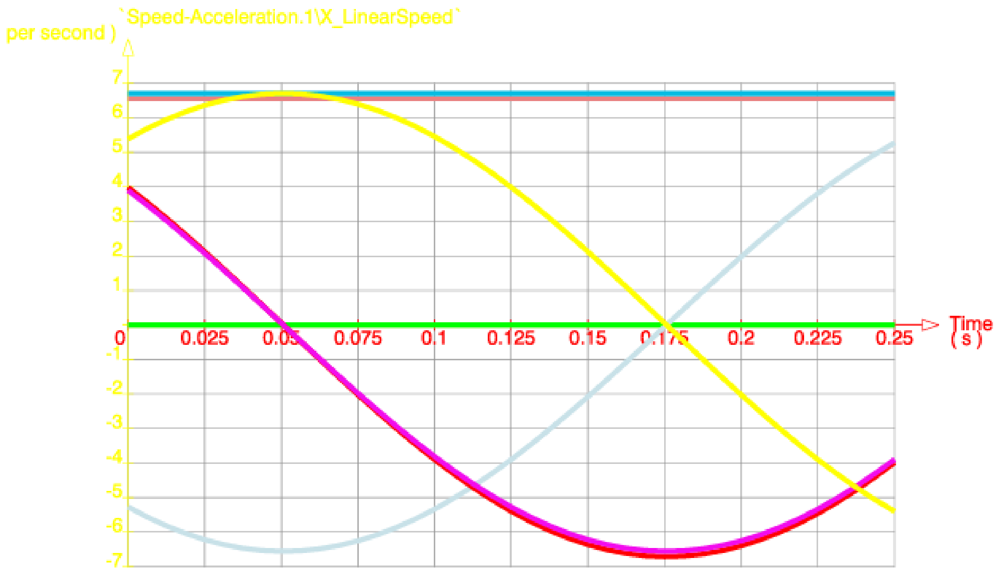

Figure 9. X Linear Speed

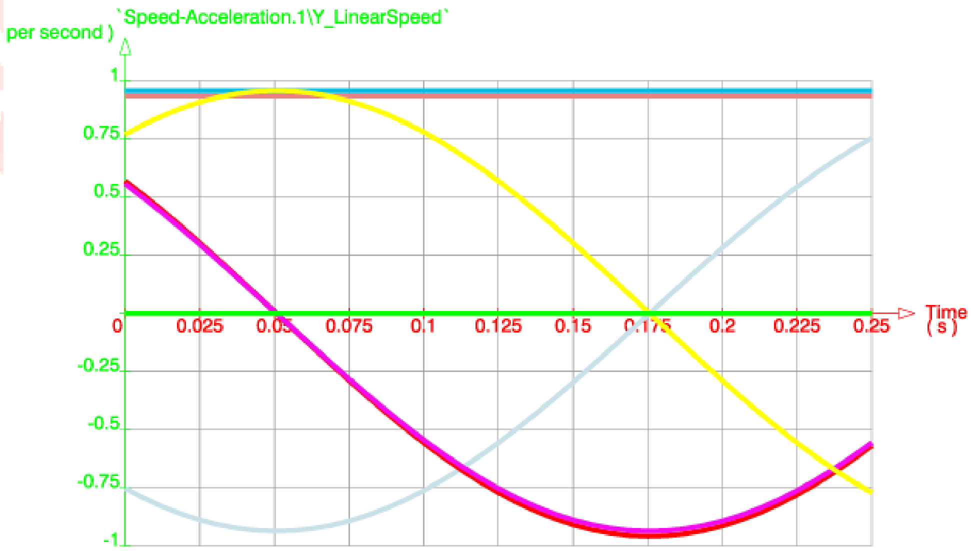

Figure 10. Y Linear Speed

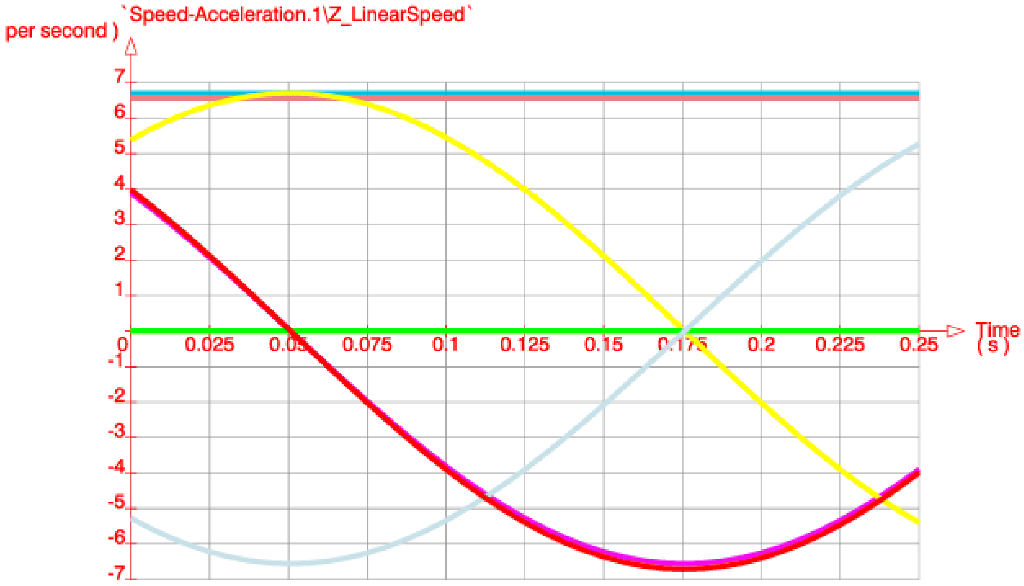

Figure 11. Z Linear Speed

2. Linear Acceleration Graph:

Expected Behavior:

Acceleration is the rate of change of speed. A sharp turn induces:

Positive acceleration at the start (as motion begins)

Negative acceleration (deceleration) toward the end to stop the rotation.

Expect two main peaks:

A positive spike at start (acceleration)

A negative spike at end (deceleration)

In x or y axis, depending on the rotation plane, you’ll see these spikes.

Z-axis should stay mostly flat unless there's vertical movement or vibration.

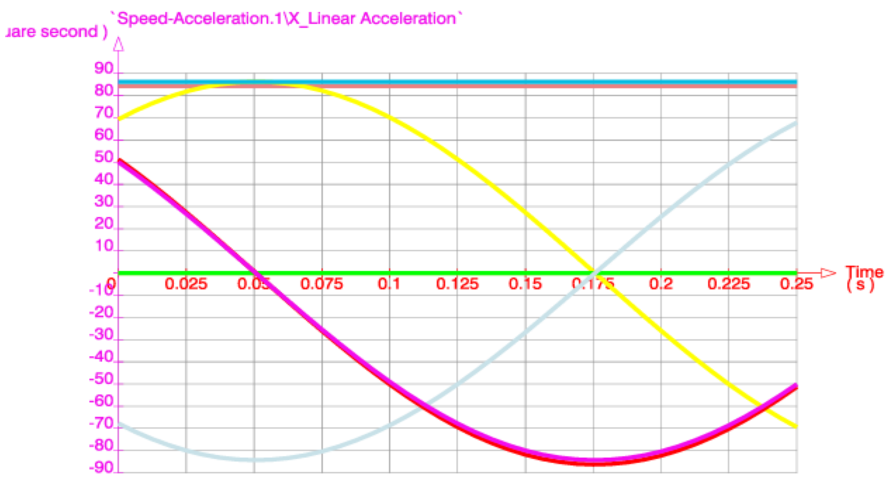

Figure 12. X Linear Acceleration

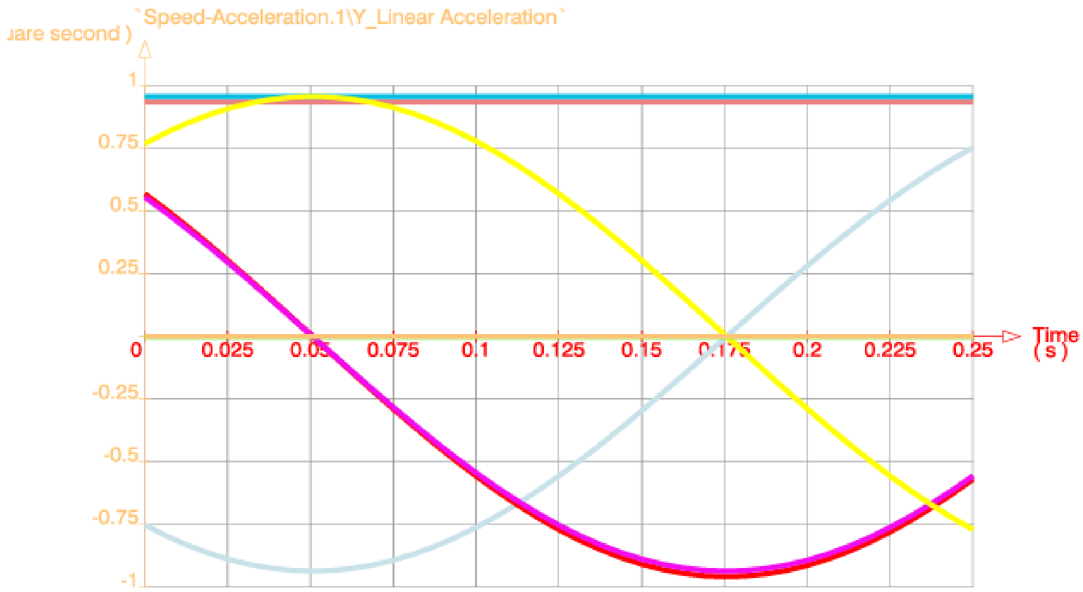

Figure 13. Y Linear Acceleration

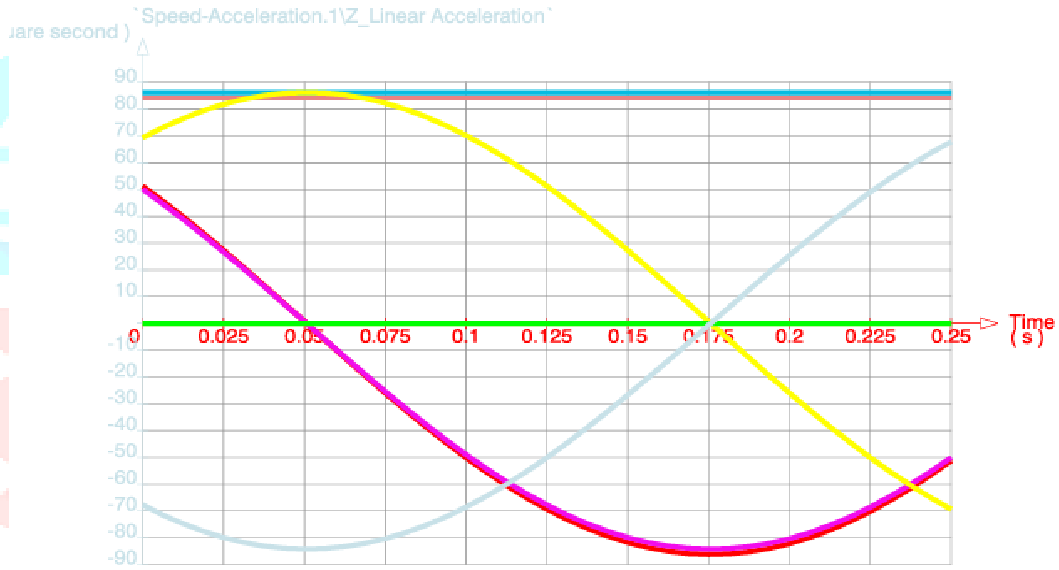

Figure 14. Z Linear Acceleration

VI. CONCLUSION

This research paper demonstrates that a wireless gesture-controlled robotic arm can be effectively simulated using CATIA and MATLAB/Simulink. The proposed design offers a reliable and responsive control mechanism suitable for applications in prosthetics, automation, and remote robotics. Future work will focus on implementing real-time wireless sensor input using microcontrollers and integrating AI for adaptive control.

The simulation and system design presented in this research paper demonstrate a functional and effective prototype of a wireless, gesture-controlled 5DOF robotic arm using CATIA and MATLAB/Simulink. By combining mechanical modelling and real-time control logic, the system successfully replicates human arm movements through intelligent signal processing. The simulation outcomes show that the robotic arm responds accurately to hand gestures, with minimal latency, making it suitable for a wide range of applications.

From a mechanical standpoint, CATIA provided high-fidelity modelling and kinematic verification of the robotic arm, ensuring smooth articulation within safe limits of motion. The integration of simulated sensor data, such as from flex sensors or IMUs, into the MATLAB environment enabled precise control of each degree of freedom. Live plots in Simulink validated the dynamic behaviour and responsiveness of the control system.

This research paper confirms that virtual simulation tools can be reliably used to develop and validate complex robotic systems before physical prototyping, reducing cost, development time, and errors. Moreover, this project lays the foundation for a real-time embedded implementation using wireless microcontrollers, sensor gloves, and servo interfaces.

Future Scope:

- Integrating real sensor inputs from a wearable glove.
- Optimizing control algorithms using AI/ML for adaptive gesture interpretation.
- Deploying the system on a physical robotic prototype for testing in real-world scenarios such as prosthetics, hazardous environments, or remote manipulation.

Overall, this study contributes a step forward in the field of human-robot interaction and intelligent control systems, highlighting the potential of gesture-based robotic manipulation for next-generation assistive and industrial applications.

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