Design and Implementation of a Hand Gesture-Based Robotic Arm Using Flex Sensor and MPU6050 Sensor

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Keywords
Arduino Nano, MPU6050, hand gesture control, disability

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Abstrak
A The advancement of robotics technology has driven innovation across various sectors, including the development of robotic arms to support human activities, particularly for individuals with disabilities. This study aims to design and implement a robotic arm that can be controlled in real time through hand gestures using the MPU6050 sensor and Arduino Uno microcontroller. The main problem addressed is how to create an intuitive and effective control system capable of accurately representing hand movements. This is an applied research project that begins with the design of a 4DOF robotic arm mechanism, followed by hardware integration, Arduino programming, and performance testing. Hand movement data is collected through an IMU (MPU6050) sensor mounted on a glove, which is calibrated to detect the user's hand motions. The analysis focuses on the accuracy and stability of the system's response in mimicking basic human arm movements. The results indicate that the system can perform its control functions well, despite challenges related to sensor accuracy and the limited processing power of the Arduino Nano. This research is expected to contribute to the development of affordable and user-friendly assistive technologies that are accessible to the broader public.

1. Introduction

The development of technology in the field of robotics has made significant contributions to various aspects of life, particularly in the industrial and healthcare sectors. One innovation that has attracted attention is the use of robotic arms, which have a wide range of applications, from manufacturing industries to medical fields. The main goal is to facilitate human tasks, as robotic technology has now spread across many areas, including the military, offices, industries, healthcare, and even the entertainment world. In the industrial world, for example, robots are used in various fields such as moving goods, assembling components in electronic equipment, and more.

One of the most commonly used components in robotics is the robotic arm. The advantage of a robotic arm lies in its high accuracy and ability to work efficiently (Utomo, 2020). Currently, robotic arms still utilize conventional controllers that require complex programming and are difficult to operate for lay users.
The design and implementation of a Robotic Arm Based on Hand Movement Using Arduino Nano was chosen due to the need for a more intuitive and user-friendly robotic control system. This approach offers a more practical solution that is accessible to a wider audience, not just professionals in the engineering field. Additionally, the use of Arduino Nano as a controller provides flexibility and ease of implementation, as well as a lower cost compared to conventional robotic solutions.

This research is applicative in nature, aiming to design and implement a robotic arm that can be controlled by human hand movements. The main objective is to create an intuitive and effective control system, allowing users to operate the robotic arm without requiring advanced technical skills. This study develops a prototype robotic arm controlled by hand motion sensors. Arduino Nano will be used as the main controller to process sensor data and actuate the robotic arm. The research stages include the design of the robotic arm mechanism, Arduino Nano programming, integration of hand motion sensors, as well as testing and evaluation of the overall system performance (A.Kurniawa, 2022)

This research is supported by various relevant theories, including those related to robotic control, sensor signal processing, and mechanical principles associated with the movement of robotic arms. Furthermore, previous studies involving the use of Arduino in robotic systems also serve as a strong foundation for the development of this system.

1.1 Literature Review

The obstacle in operating the robot arm is that it requires difficult programming for laypeople by creating a 4 DOF robot arm control system that is controlled by hand movements using the MPU-6050 sensor and potentiometer without the need for complicated programming. The purpose of this study is to create an easy-to-use control system, where the robot arm can be controlled simply by moving the hand and pressing the button. The advantage of the hand movement-based control system is that it makes robot operation easier, while the disadvantage of this study is that it is limited to DOF robot arms, it has not been tested on more complex applications or on robot arms with higher DOF. (Utomo, 2020)

In Kurniawa's research, the research problem is to create responsive and precise robotic control using conventional sensor technology. The SS49E Linear Hall Effect sensor is used to detect changes in magnetic fields and convert them into smoother and more accurate robotic movements. The purpose of this research is to design and implement a robotic hand control system that uses a Linear Hall Effect sensor to improve the precision and responsiveness of movements (A. Kurniawa, 2022).

The challenge of precisely controlling a robotic hand using gestures as control input is challenging. Gesture-based sensors, such as accelerometers and gyroscopes, are used to detect hand movements and translate them into robotic motion. The aim of this research is to develop a gesture-based robotic hand control system capable of capturing the user's natural movements and translating them into robotic motion (K. Duraisamy, 2022).

2. Result and Discussion

2.1. Research Method

This section presents the methodology used in designing and implementing a hand gesture-based robotic arm using Arduino Uno and the MPU6050 sensor. The research method is structured to provide clarity and reproducibility for readers interested in replicating the system. It includes the flow of research, tools and materials used, and other relevant aspects.

The system was primarily designed for individuals with physical disabilities, particularly those affected by mild strokes or cerebral palsy. These users often experience limitations in arm and hand mobility, and thus require assistive devices that are intuitive, real-time responsive, and easy to use. Although direct user testing with individuals with disabilities was not conducted due to scope limitations, the design principles and user needs were based on existing literature and simulation scenarios in a laboratory setting.

2.1.1. Data Collection

The data collection process consisted of several stages:

- System Setup: Assembly of the hardware components, including the MPU6050 sensor, servo motors, Arduino Uno, breadboard, and 3D-printed robotic arm.
- Sensor Calibration: Calibration of the MPU6050 to ensure accurate detection of pitch, roll, and yaw corresponding to hand movements.

- Motion Data Recording: Hand motion data was collected using a glove embedded with the MPU6050 sensor, covering basic movements such as tilting (left/right, up/down).
- System Response Logging: Real-time testing was conducted to observe the robotic arm's responses to the user's hand movements.

2.1.2. Data Validity and Reliability

To ensure the system's consistency and reliability:

- White-box testing was performed to validate the logic in the Arduino code, including initialization, sensor data mapping, and servo control.
- Black-box testing was used to evaluate the system's functionality from a user perspective—whether the robotic arm responded correctly to hand inputs.
- Sensor calibration was repeated several times to ensure stability.
- Multiple iterations were conducted to improve accuracy by adjusting sensitivity gains and implementing signal smoothing.

2.1.3. Research Flow

The research followed a structured approach as described below:

- Design Phase: Designing a robotic arm with 4 Degrees of Freedom (DOF) using CAD tools., Planning the circuit schematic involving MPU6050 and servo control via Arduino Uno.
- Hardware Implementation: Building the prototype using 3D-printed parts, servos, and connecting the glove sensor system, Power supply integration using external 5V DC for servos.
- Software Development: Coding in Arduino IDE using libraries such as Wire.h, Servo.h, and MPU6050.h. Processing hand gestures into servo motion via mapping functions and angle constraints.
- Testing and Evaluation: Conducting lab-based testing of basic hand movements.
- Logging output behavior (servo angle change, motion lag).
- Documenting results with visual evidence and analyzing performance metrics.

2.1.4. Tools and Materials

The following components were used:

- Arduino Uno – microcontroller for processing sensor input and controlling servos.
- MPU6050 – Inertial Measurement Unit combining accelerometer and gyroscope.
- Servo motors (4 pcs) – Actuators to move robotic arm segments.
- Flex sensor – To detect finger bending for gripper control.
- 3D-printed robotic arm – Custom-designed for 4DOF.
- Glove – Embedded with MPU6050 and flex sensors.
- Breadboard and wiring – For circuit prototyping.
- Power supply (5V DC 1A) – Dedicated to servo power.

2.2. Discussions

The prototype of the hand gesture-based robotic arm was successfully implemented and tested in a controlled lab environment. The robotic arm responded effectively to the real-time input from the MPU6050 sensor mounted on a glove, translating pitch and roll hand gestures into mechanical movements via servo motors. During the black-box testing, the system demonstrated functional accuracy in executing basic commands such as:

- Left-right movement (yaw)
- Up-down movement (pitch)
- Gripper control via flex sensor

The response time was consistently under 0.5 seconds, and the servo motors smoothly followed the mapped input angles. This indicates good system responsiveness and low latency, which is critical in assistive applications.

The **white-box testing** also confirmed that:

- Sensor readings were correctly mapped and constrained within servo-safe ranges (0–180°).
- Smoothing algorithms successfully reduced jitter from raw sensor data.
- Logical branches for gesture recognition performed consistently under all defined test conditions.

Compared to similar studies such as that by Rodriguez (2020) which utilized EMG sensors, this research offers a lower-cost and less complex solution while still maintaining effective motion replication. The work of Utomo (2020) also highlighted gesture-based control, but with fewer DOF and less integration of gripper mechanisms. This study's integration of a flex sensor for finger input, in addition to IMU-based motion, provides more natural and intuitive interaction, making the system more suitable for individuals with physical disabilities—especially those with partial hand mobility. However, challenges were encountered:

- Sensor drift over prolonged use, causing offset in positioning.
- Physical limitations in 3D-printed joints under load stress.
- Limited gesture complexity due to only one flex sensor used.

Nevertheless, the results demonstrate the feasibility of the design and highlight its potential for low-cost assistive robotic solutions.

3. Conclusions

This research successfully designed and implemented a 4DOF robotic arm controlled by hand gestures using the MPU6050 sensor and Arduino Uno. The system responds in real-time to user movements, allowing users—especially individuals with disabilities—to perform basic arm functions more independently.

The results show that the integration of the MPU6050 sensor and servo actuators provides adequate performance in mimicking human arm motion. The use of a flex sensor to control the gripper further enhances interaction. Despite some limitations in sensor accuracy and mechanical strength, the system was stable and accurate during testing, with minimal delay and good responsiveness.

In future work, several enhancements can be considered:

- Integration of wireless communication modules (e.g., Bluetooth) for better mobility.
- Use of multiple flex sensors for finer control over each finger.
- Implementation of advanced filtering algorithms such as Kalman Filters for sensor stability.
- Application of machine learning to expand gesture recognition capabilities.
- Real-world testing with actual users with physical impairments to validate effectiveness and usability in daily tasks.

This study lays a strong foundation for affordable, user-friendly assistive robotics development, with promising potential for rehabilitation and independent living support.

4. References

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