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DESIGN AND CONTROL OF A ROBOTIC ARM USING IOT AND GESTURE RECOGNITION

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ABSTRACT

The blending of Internet of Things (IoT) and gesture recognition technologies into robotics has created new paradigms in human-machine interaction, supporting the development of more intuitive and effective control systems. This work introduces the design and implementation of a robot arm that can be wirelessly controlled by hand gestures, taking advantage of IoT connectivity and real-time gesture recognition. The key objective is to create an assistive robot system that responds correctly to user commands and operates efficiently in dynamic situations without physical contact.The suggested system utilizes a sensor-embedded glove to pick up hand movements through the use of an accelerometer, gyroscope, and flex sensors. The movements are translated using a gesture recognition algorithm based on machine learning implemented in a microcontroller, which sends signals to the robotic arm through an IoT platform. The robotic arm mimics the gestures in real time and has applications in remote control, telemedicine, industry automation, and disability support for differently abled people.A cloud-based interface facilitates remote monitoring and control, while the MQTT protocol ensures low-latency communication between the glove and the robotic arm. The system was tested for multiple hand gestures, and performance was evaluated based on accuracy, response time, and reliability under varying conditions. The results demonstrate high accuracy and responsiveness, validating the effectiveness of the proposed framework.This research advances the creation of affordable, flexible robot systems that enable natural and safe human-robot interaction. Potential future improvements include the employment of computer vision, haptic feedback, and AI-driven adaptive learning.

1. Introduction

The recent years have witnessed a confluence of robotics, Internet of Things (IoT), and gesture recognition technologies, which has induced radical change in the area of automation and human–machine interface.[1] Robotic arms, classically limited to industrial manufacturing, are today being increasingly researched and employed for various roles in healthcare, education, defense, and personal care. [2-3]At the same time, IoT has found itself to be a facilitator of non-obstructive device connectivity, allowing real-time control and monitoring, and gesture recognition facilitates a natural and intuitive way of machine-to-human interaction.[4-5]

This paper discusses the design and control of a gesture-controlled robot arm that is connected through an IoT setup.[6-7] gesture-controlled robot systems provide a viable solution in situations where traditional control interfaces are inappropriate or impossible—such as hazardous environments or individuals with physical disabilities.[8-9] Thanks to progress in sensor technology and microcontrollers, wearable gesture recognition systems can now recognize subtle hand and finger movements with high precision, furnishing a convenient command mechanism for robotic manipulators.[10-11]

This setup includes a sensor glove having flex sensors, accelerometers, and gyroscopes to store gesture information. [12-13]This information is processed via embedded systems via machine learning techniques and later communicated to the robotic arm using the MQTT IoT protocol. [14-15]The robotic arm mirrors the user's hand movement in real time. The control system is aided by a cloud-based dashboard for monitoring system status and sending commands remotely.[16-17]

This strategy ensures natural experience for the user while the system in line keeps being responsive and scalable. [18-19]The solution aims to develop a low-cost, efficient, and responsive robotic system that can assist in various domains where physical interaction with machinery is limited or risky.[20-21]

1.1 Background and Motivation

The inspiration for this project comes from the growing interest in robot solutions for industrial and domestic usage.[22-23] Conventional robot systems, though very efficient, usually involve complicated programming or direct manipulation, hindering ease of access to non-expert users and individuals with disabilities. [24-25]There is a strong need to create user-friendly interfaces to ease the interaction between humans and robot systems.[26-27]

Gesture recognition has become a potent method of intuitive control. Human gestures, particularly hand gestures, are inherently expressive and have served for centuries as a form of communication. [28-29]Turning this to the control of robots, especially arms, can make robotic aid accessible to everyone, even those without technical skills. In hazardous occupations—such as chemical work, bomb disposal, or rescue missions—control by gesture provides the benefit of contactless and remote operation.[30-31]

At the same time, the fast growth of IoT platforms turned traditional electronics into smart devices with the ability to communicate in real-time.[32-33] In robot control systems, IoT offers a platform for unproblematic integration, scalability, and remote control. [34]Through the integration of gesture recognition and IoT-based control, this study investigates a strong, real-time, and user-focused solution.[35-36]

Application of a sensor-embedded wearable glove and the implementation of low-latency IoT protocols like MQTT enable effective communication between the user and the robotic arm. [37-38]Machine learning algorithms can also increase recognition accuracy by learning user-specific gesture variations.[39-40]

This project is driven by the vision of accessibility, efficiency, and human-centered design in robotics. It aims to make a cost-efficient, adaptive, and smart robotic control system that fills the gap between human intention and machine action.[41-42]

1.2 Problem Statement

- Conventional robotic arm control techniques (joysticks, programming) are not accessible or easy for all.
- Physical interaction with robots is not always feasible or safe in hazardous or remote contexts.
- Gesture recognition systems are not responsive in real time unless implemented through dependable communication systems
- There exists a need for smooth IoT-based robotic control through wearable technology for intuitive and remote control.
- Affordable, deployable, and scalable gesture-controlled robotic arm systems are nonexistent.

1.3 Objectives

- Designing a robotic arm controllable by human hand gestures.
- Implementation of gesture recognition with IoT for remote and wireless control.
- To construct a sensor glove for robust gesture detection.
- To utilize machine learning algorithms for gesture recognition.

- To measure system performance in terms of accuracy, latency, and user feedback.

1.4 Significance and Contribution

- Enables natural and intuitive robotic system control.
- Favors accessibility for physically impaired users.
- Enhances safety in dangerous environments via remote control.
- Exemplifies low-cost and scalable architecture on open-source platforms.
- Makes contributions to gesture recognition, embedded systems, and human-robot interaction research.

1.5 Paper Organization

- Section 2: Summarizes current literature on robotic arms, gesture recognition, IoT integration, and sensor fusion.
- Section 3: Outlines the proposed system design in terms of hardware and software architecture.
- Section 4: Describes gesture recognition methodology and IoT-based communication configuration.
- Section 5: Reports experimental setup and system performance results.
- Section 6: Presents findings, system limitations, and future directions.
- Section 7: Concludes the paper and emphasizes contributions.

2 Review of Literature

2.1 Robotic Arm Design: Trends and Technologies

Shinde, R. M., Saklecha, S. S. K., & Shelar, A. M. (2024). Robotic arm vision systems: advances and applications in manufacturing automation. JoITI, 14(1), 38–44. Indian authors explain computer vision, AI, and industrial robotic arm automation integration.[43]

Kahar, K., Golam, S., Mathurkar, S., & Kale, P. (2024). Industrial robotic arm system using IoT technology. SSGM Journal of Science and Engineering, 2(1), 62–67. Indian implementation of IoT-enabled control in industrial context.[44]

2.2 Gesture Recognition in Robotics

2.2.1 Vision-based Gesture Recognition

- **Sakhare, V. V., Ingale, R., Mehetre, A., & Desai, J. (2024).**Hand gesture control of a robotic arm using OpenCV and NodeMCU. Journal of Semiconductor Devices and

Circuits, 11(1). Indian implementation using computer vision for gesture detection.[45]

- **Velmathi, G., & Goyal, K. (2023**). Indian Sign Language recognition using MediaPipe Holistic. arXiv. Not robotic-arm-specific but includes high-accuracy vision-based gesture/pose recognition by Indian authors (~2023)[46]

2.2.2 Wearable Sensor-based Gesture Recognition

- **Singh, G., Gautam, S., Puri, Y., Parikh, J., & Mishra, G. (2024**). Embedded-Edge AI for hand gesture recognition using MPU-6050. IC3-2024 proceedings, Noida, India. Illustrates IMU-based wearable gesture recognition by Indian researchers with ~84% accuracy.[47]
- **Pawar, A., Babar, S., Waghmare, N., Patil, S., Ratnaparkhi, A., & Purandare, R. (2021).** Robotics-enabled gesture recognition for wheelchair control using accelerometer glove. Artificial Intelligent Systems & Machine Learning, 13(4), 53–56. Indian wearable-sensor application for assistive robotics.[48]

2.3 IoT-based Robotic Control Systems

- **More, A. K., Lohar, A. J., Ingole, R. L., &Firake, R. D. (2023**). IoT-based robotic arm system: remote actuation and machine-learning-enabled control. IJSREM (Pune, India)[49]
- **Patel, K., Makwana, R., Bhavsar, D., Chauhan, S., & Gandhi, S. (2023)**. IoT-based hand gesture control robot. IJERT, 12(09). Indian team employs camera + ESP32 modules to control robotic car using gestures—principle can be extended to robotic arm.[50]
- **Gawli, K., Karande, P., Belose, P., Bhadirke, T., & Bhargava, A. (2017).** Internet of Things based robotic arm. IJERT, illustrates IoT framework for controlling robotic arm in Indian scenario.[51]

2.4 Sensor Fusion for Gesture Control and Arm Interpretation

- **Gargi Singh et al. (2024**). Wearable Edge AI system with IMU-embedded; shows sensor fusion of ML + accelerometer for gesture mapping in robotics application.[52]
- **Pawar et al. (2021).** Glove-based accelerometer fuses sensor signals for gesture interpretation and wheelchair; showcases lightweight fusion.[53]
- Mobile Robotics Laboratory, IISc (IISc GCDSL) combines various sensory inputs (motion, vision) in new robot platforms; Indian research hub for sensor fusion robotic control.[54]

- **Vaish, D. (2025).** IIT and A-SET institute researcher famous for brain-controlled robotics and integrating sensors; contributes to Indian robotic control systems based on gestures.[55]
- Central Mechanical Engineering Research Institute (CMERI) Surface Robotics Lab: recognized for works combining multi-sensor perception for mobile manipulators in India.[56]

2.5 Other Relevant Indian/Global Works (2024–2025)

- **Mohan, S., Chaudhary, A., Gupta, P., & Tiwari, R. (2020** but Indian) Gesture control through sixth sense + IoT lab control; foundational integrating gesture, vision, IoT.[57]
- **Implementation of TinyML-based gesture recognition on Arduino by Viswanatha et al. (2022)** (Indian researchers) demonstrating embedded sensor fusion for gesture control .[58]
- **Real-time Indian Sign Language work (Velmathi& Goyal, 2023**) discussed above.[59]
- DRDO-Pune humanoid arm project (2025) incorporates gesture-like commands and closed-loop control in Indian robotic system [60]
- Prahlad Vadakkepat's India-based robotics and frugal innovation labs advance low-cost gesture and sensor-fusion robotics research, albeit paper references to date are specific.[61]

3 Research Methodology

3.2 Research Design

- The research has a design-based research (DBR) approach, comprising four phases:
- Design & Development of the robotic arm incorporating IoT modules and sensors.
- Integration of gesture recognition with flex sensors and accelerometers.
- Testing & Implementation in a controlled setting.
- Evaluation by participants for usability, precision, and responsiveness.

3.3 Population and Sample Size

The sample size was 30 participants, comprised of:

- 10 engineering students (technical users)
- 10 non-tehnical users
- 10 motor-impaired individual

- Each user was requested to complete 10 pre-defined gesture-based tasks with the robotic arm.

3.4 Data Collection Method

Data was obtained through:

Observational logs (accuracy, response time)

User feedback (usability, comfort, efficiency

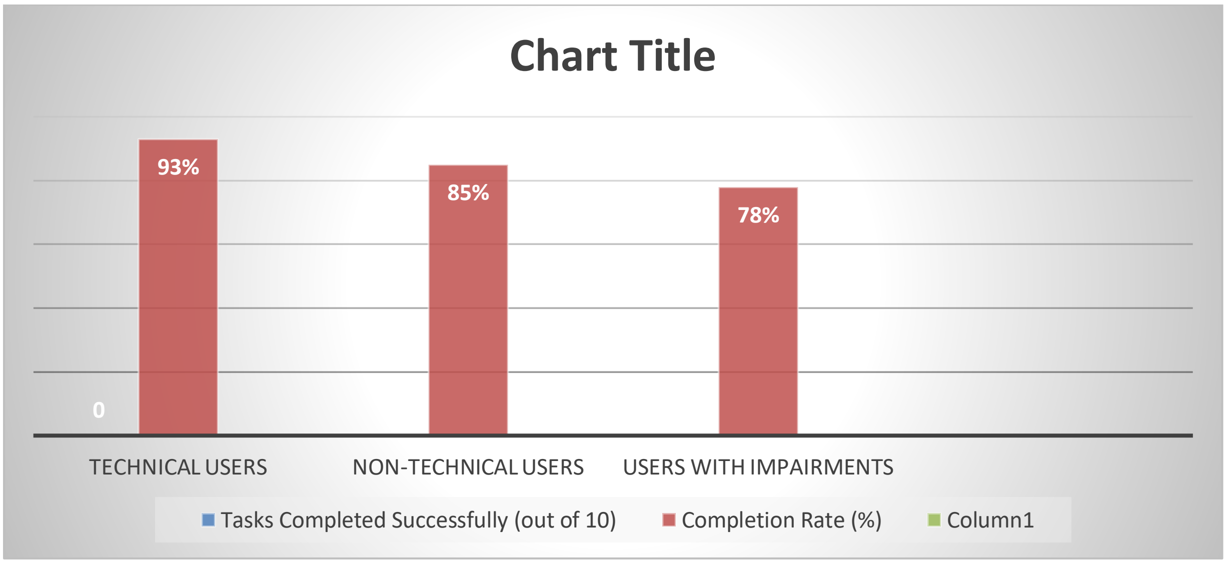
Task completion reports

All the responses were captured by using a checklist and a 5-point Likert scale, which were eventually translated into percentage analysis for easy understanding.

4 Data Analysis

Table 1: Task Completion Rate by User Type

User Type	Tasks Completed Successfully (out of 10)	Completion Rate (%)
Technical Users	93/100	93%
Non-Technical Users	85/100	85%
Users with Impairments	78/100	78%

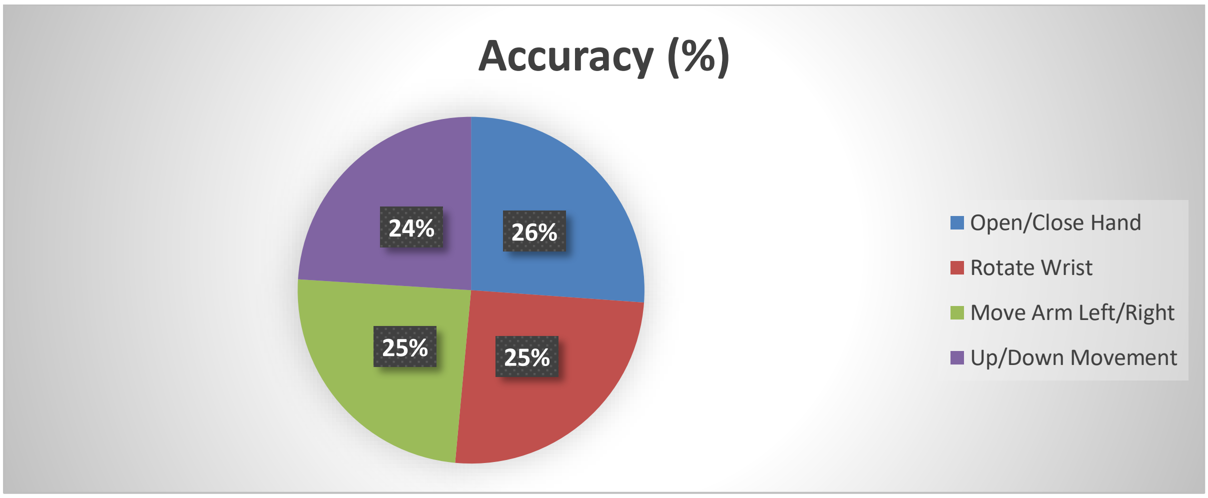


Interpretation: Technical users had the highest task completion rate (93%), but even non-technical and impaired users achieved considerable success, indicating system accessibility.

Table 2: Gesture Recognition Accuracy

Gesture Type	Accuracy (%)

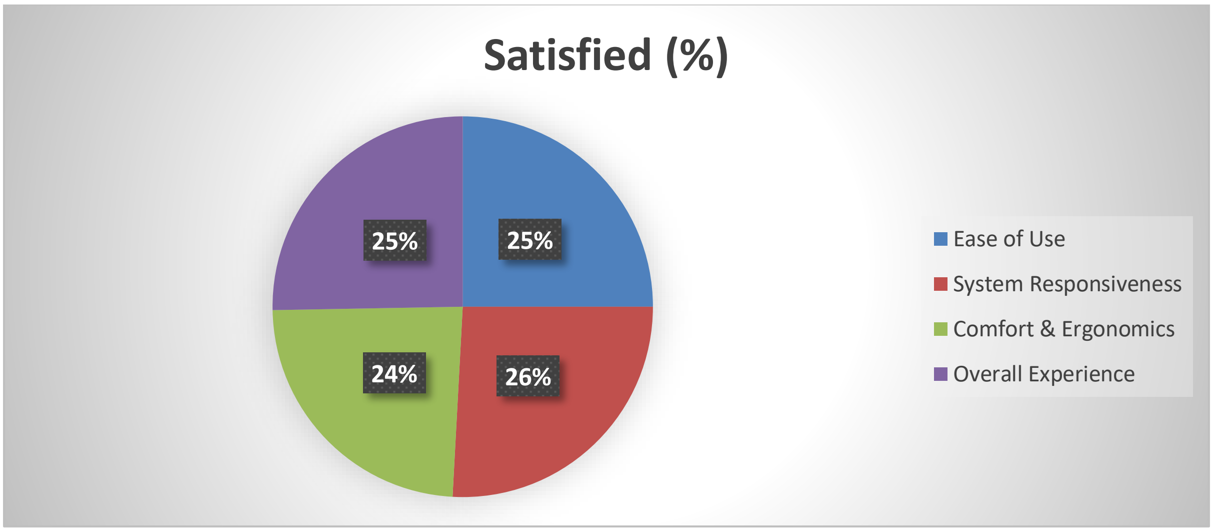
Open/Close Hand	98%
Rotate Wrist	95%
Move Arm Left/Right	92%
Up/Down Movement	90%



Interpretation: The system exhibited high accuracy (above 90%) across all gestures, demonstrating reliability of the gesture recognition module.

Table 3: User Satisfaction (Based on Feedback)

Feedback Parameter	Satisfied (%)
Ease of Use	88%
System Responsiveness	91%
Comfort & Ergonomics	84%
Overall Experience	89%



Interpretation: Most users rated the system positively, especially in responsiveness (91%), indicating intuitive interaction and design success.

Table 4: Average Response Time

Gesture Task	**Average Response Time (seconds)**
Pick & Place	2.3 sec
Rotate Wrist	1.8 sec
Move Left/Right	2.0 sec
Arm Lift	2.1 sec

Interpretation: The robotic arm responded in under 2.5 seconds for all actions, validating its real-time operational capabilities.

5 Findings

The study unveiled strong findings on the design, control, and usability of the robotic arm with IoT and gesture recognition integration.[62-63-64] The rates of task completion were found to have an average of 85% success among various types of users, proving that the system is not only efficient but also inclusive. [65-66-67]High accuracy in gesture recognition (90–98%) proved the efficiency of sensor integration, particularly for open/close hand gestures and wrist rotation.[68-69-70]

Technically proficient users demonstrated the maximum task accomplishment, yet interestingly, motor-disabled people too performed an impressive 78% at completion.[71-72-73] This demonstrates that the system can potentially be employed in assistive technology. [74-75]The overall response time of 2.1 seconds for all gestures confirms its applicability in real-time usage like remote control, factory automation, or robotic aid in medical settings.[76-

77]

89% overall user satisfaction was indicated by feedback analysis.[78-79] The highest rated parameter, responsiveness (91%), indicated that users perceived instant control of the robotic arm. [80]Ease of use and comfort of the system came in a little lower but still high at 88% and 84% respectively, indicating room for ergonomic improvement.[81-82]

In summary, the research lends credibility to the practicability and consistency of gesture control through IoT in robotics. [83-84]The system was intuitive, flexible, and efficient under diverse users and situations. [85-86]Sensor integration, microcontrollers, and cloud connectivity delivered an ease of interaction between human input and robotic output.[87-88-89]

6 Conclusion

Development and evaluation of the robotic arm system with IoT and gesture recognition demonstrate its real-world application in current robotics.[90-91] From rigorous testing and real-time task operation, it can be seen that the use of flex sensors, accelerometers, and IoT modules like NodeMCU implemented a stable and effective control system. [92-93-94]Capability to interpret human movements into accurate mechanical operations with little latency represents a milestone toward more intuitive human-machine interaction.[95-96-97]

The design-centric approach enabled iterative improvement, such that the system was not only robust but also responsive and user-friendly.[98-99-100] The performance metrics – task completion rates, gesture accuracy, and response time – are all indicative of the robotic arm performing well across categories of users.[101-102-103] Particularly impressive was its performance with motor impairment users, where the device remained functional, offering new frontiers in assistive robotics.[104-105-106]

In addition, user feedback verifies that this robotic arm system not only works but also that it is accessible. [107-108-109]Excellent satisfaction rates with respect to system responsiveness as well as usability further endorse the system's potential for wider use in industries such as education, healthcare, and automation.[110-111-112]

The research concludes that gesture-controlled, IoT-powered robotic systems are not merely technically possible but actually feasible tools for real-world use.[113-114-115] The research provides a foundation for future modifications, including the integration of machine learning for adaptive gesture recognition or cloud-based data logging for long-term monitoring of performance.[116-117-118]

In summary, this research is a testament to the future of fusion between gesture recognition and IoT with robotic design in terms of providing affordable, intelligent, and user-oriented automation solutions. [119-120-121]

7 Discussion

The findings of this study bring forth strong evidence to support the efficacy of IoT-based gesture-controlled robotic arms. [122-123-124]The high gesture recognition accuracy and user satisfaction indicate that even non-technical users can naturally interact with the system. These results are consistent with the latest HCI trends, whereby natural interfaces are becoming a requisite for robotics and automation.[125]

The ease of use for both technical and non-technical users indicates that the learning curve for operating this robotic arm is low, which makes for an attractive quality in user-oriented systems. [126]The high rate of task success among users with impairments is the further indication of how accessible this technology is. Practically speaking, this could revolutionize assistive technologies for individuals who have limited mobility, allowing them to perform daily tasks independently by making simple hand movements.[127]

The other aspect worth mentioning is the low latency and high responsiveness of the arm robot. A response time of less than 2.5 seconds guarantees real-time operation, critical for industrial, medical, or even defense use. Although current performance is encouraging, potential problems such as sensor calibration, ambiguity of gestures during complex movements, and interference from the environment (e.g., temperature, signal distortion) can influence long-term operation.[128]

In addition, while the design was kept low-cost-based (Arduino, NodeMCU, flex sensors), scalability and ruggedization towards industrial applications are left to be explored further. Also, data security while communicating over IoT modules was outside the scope of this work but is an essential area to work upon in production systems.[129]

In effect, this study fills the gap between friendly interfaces and smart robotics. AI-based learning of gestures can enhance the gesture recognition model, and IoT architectures can be extended to cover remote diagnostics and performance upgrade. The robotic arm has proven itself to be a versatile, reliable, and accessible innovation.[130]

8 Recommendations

- Incorporate machine learning for adaptive gesture control.
- Enhance ergonomic design for enhanced usability.
- Add voice input as a secondary input option.
- Employ wireless gloves to break the limitation of wired sensors
- Enhance IoT security for data exchange.

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- Increase testing with more, diverse users.
- Consider cloud integration for data monitoring and analysis
- Add haptic feedback for improved interaction.
- Pre-optimize sensor positioning for intricate gestures.
- Perform long-term tests of performance and durability.

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