

# Humanoid Left Arm Collaboration Empowered by IoT and Synchronization of Human Joints

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A robotic left arm has been developed in this research to assist individuals in safely navigating hazardous environments, utilizing Internet of Things (IoT) technology to synchronize its movements with those of a human operator in real-time. The primary objective of this work was to enhance the precision and responsiveness of the arm. Sensors and microcontrollers (ESP32, Arduino UNO) were integrated into the robotic arm to collect and transmit movement data. Advanced machine learning algorithms, including Inverse Kinematics, Reinforcement Learning, and Deep Learning, were employed to facilitate the arm's learning process and improve its actions. The system was evaluated in simulated hazardous scenarios to assess its performance. The results indicate that the robotic arm can adjust and move accurately, aligning with the human operator's arm movements. The robotic arm safely manages hazardous materials, demonstrating high precision in executing complex tasks. These findings underscore the effectiveness and safety enhancement achieved by integrating IoT and intelligent algorithms into robotic systems for high-risk occupations. This technology significantly enhances emergency response capabilities and critical operations, delivering dependable and precise robotic assistance. Overall, this research underscores the potential of IoT-enabled robotic arms to revolutionize human-robot interactions in demanding environments. By showcasing how real-time synchronization and advanced algorithms enhance the functionality and safety of robotic systems, this research presents a promising solution for strengthening the operational safety and efficiency in hazardous situations. The development and utilization of this technology represent substantial progress in fields necessitating precise and dependable robotic assistance, ultimately promoting improved collaboration between humans and robots in high-risk contexts.

**Keywords:** High-risk environment, Humanoid robot, Human-robot interaction, Real-time synchronization, Robotic arm

## Introduction

Robots have come a long way, making it easier to use resources smartly, speed up production, cut costs, and do tasks that humans can't do as well. They're essential in keeping emergency workers safe during disasters because they can adapt and work precisely in dangerous situations. This progress is changing how we manage resources and produce goods while also highlighting how robots help protect people in harsh conditions. Humans have limits in extreme or risky environments, but robots controlled by the Internet of Things (IoT) can adapt better, work more precisely, and keep people safer. The study of ergonomics, which looks at how people interact with their environment, helps design these humanoid robots by considering human body measurements, movement, and mental and physical needs. Collaborative robots, or cobots, are a big step forward. They work alongside humans, combining human skills with robotic efficiency. This teamwork ensures tasks are

done perfectly in areas where human touch is still necessary, marking a significant change in how we use robots in different fields.

Our research explicitly addresses disaster response, industrial accidents, and hazardous material handling scenarios, where humanoid robots can significantly enhance safety and efficiency. By providing real-time synchronization and control, our study fills a critical gap in the current robotic technology landscape, particularly in high-risk environments.

Significant strides have been made in developing robotic arms and humanoid robots in recent years, yet persistent gaps need addressing. For instance, Pravin *et al.*<sup>1</sup> emphasized the importance of gyroscopic acceleration sensors for the 360° movement of robotic arms. These sensors enhance balance and stability, yet their study lacks a comprehensive approach to optimizing the algorithms processing this data. This gap suggests a need for further research into advanced software solutions that can fully use these sensors, enabling more precise and adaptable robotic motion control in various operational contexts.

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Similarly, Khaleghi *et al.*<sup>2</sup> investigated using actuators, sensors, and cameras for controlling robotic hand gestures through a neural network trained on 26,000 images. While their work demonstrates significant progress in gesture recognition, it does not sufficiently address real-time processing and latency challenges, which are critical for practical applications. Exploring solutions to these issues could enhance the robot's responsiveness and reliability in dynamic environments. Dutta *et al.*<sup>3</sup> developed a robotic arm to assist individuals with paralyzed lower body parts by enabling multiple degrees of freedom in movement. Their innovative design includes synchronized finger movements and five-finger rotation. However, the study does not investigate such systems' long-term durability and maintenance. Future research should focus on the materials and mechanisms that ensure the sustained functionality of these assistive devices under continuous operation. Maurice *et al.*<sup>4</sup> highlighted the role of robotic systems in preventing musculoskeletal disorders by performing physically demanding tasks. Their assessment covered balance, force, and vision but did not consider adaptive algorithms for dynamically adjusting these parameters based on real-time feedback and task requirements. Integrating adaptive learning capabilities could significantly improve the effectiveness of robots in unpredictable human environments.

While many researchers have explored enhanced communication methods between robotic systems, a comprehensive approach that considers adaptation to different contexts and varying task complexities is often missing.<sup>5,6</sup> Future studies should aim to develop scalable and adaptable communication protocols that can handle diverse robotic operations seamlessly. Sugihara *et al.*<sup>7</sup> advanced the field with algorithms enabling humanoid robots to move with human-like agility and fluidity. Their foundational work on Zero Moment Point (ZMP) and Center of Gravity (COG) algorithms was pivotal. However, they did not explore the integration of these algorithms with modern artificial intelligence and machine learning techniques. Such integration could enhance humanoid robots' cognitive and adaptive capabilities, enabling them to learn new tasks and adapt to evolving environments more effectively. In conclusion, while these studies contribute valuable insights into robotics, they also highlight areas that require further investigation. By refining motion control algorithms,

enhancing adaptability and learning capabilities, ensuring long-term durability, and optimizing communication protocols, we can significantly advance the development of more intelligent, reliable, and versatile robotic systems for practical applications.

The field of Robotics with IoT is called Internet of Robotic Things (IoRT) which links either of them. IoRT is robotics driven by IoT, an amalgamation of both disciplines. Robots can operate independently and make wise decisions, including functions such as motion and interaction with the physical environment.<sup>8-10</sup> In disaster management scenarios, IoRT can enable robots to perform search and rescue operations, identify hazards, and assist in medical emergencies without risking human lives. For a robot to become intelligent and collaborative, IoRT is the way forward. The application of IoRT includes automation in supply chain solutions, warehousing, manufacturing, e-commerce, healthcare, personal robots, disaster management and military applications. Now, this research focuses on the building, assembling and operating the humanoid robot's left arm, wherein various parts such as sensors, accelerometers, gyroscopes, boards, motors and others are deployed for the construction. Initially, the fundamentals and workings of the Arduino board will be discussed, followed by a literature review examining the research paper referred to in the context of constructing the humanoid robot. Furthermore, humanoid robots, including their working, sensing, perception, locomotion, and human-robot, will be addressed. During the construction of the humanoid robotic left Arm, every piece of hardware has its importance. For instance, the Arduino Board will act as a link between the robot and the hardware. Sensors will control the angular velocity, collect data from the physical environment, and convert it into an electrical signal. The gyroscope can handle movement up to 360° in the robot. This is how the functioning of each hardware is different yet adapted to the objectives. Moreover, the methodology will delve into various aspects such as the usage of parts, their application and deployment, characteristics and the process followed to achieve the desired result of the movement of the robotic arm.

This research addresses the gap in integrating IoT technology into humanoid robots for high-risk environments, which remains underexplored. Current robotic systems lack real-time synchronization and

precise control to assist humans in hazardous situations effectively. By developing an advanced humanoid robotic left arm, this study utilizes IoT for enhanced adaptability, precision, and safety. This research advances human-robot collaboration with a humanoid robotic left arm by:

- Showcasing cutting-edge integration of IoT and sensors.
- Demonstrating effective risk mitigation in high-risk scenarios.
- Enabling real-time collaboration between a humanoid robot’s left hand and a human’s left hand through IoT integration.

Focusing on real-time collaboration and control, our study aims to improve human-robot interactions and risk mitigation strategies in challenging environments. For example, during a chemical spill, a humanoid robot equipped with our technology can precisely handle hazardous materials, reducing the risk to human workers. Such practical applications highlight the transformative potential of our research in real-world scenarios.

This paper discusses the state-of-the-art techniques used to date and the benefits of using IoT, which can be the breakthrough to advance human-robot interaction and represent a groundbreaking use of IoT in collaborative humanoid robotics, signalling the next generation of interactive robotic systems.

Further humanoid robotics and IoT are also presented to channel the research properly, followed by the methodology, formulas used, and real-time lab images of the work done in the result section.

**Humanoid Robot**

Humanoid robots, with their anthropomorphic design and advanced capabilities, represent a cutting-edge frontier in robotics. Inspired by human form and function, these robots aim to replicate human-like movements and interactions, making them highly versatile in various applications. Fig. 1 illustrates the dynamic evolution of robotics from the 1950s to the 2020s, capturing milestones such as the introduction of industrial robotic arms, programmable robots, and the integration of Artificial Intelligence (AI). This visual chronicle showcases robotics' continuous advancement and diversification, shaping technological landscapes across various industries.

Humanoid robots showcase remarkable agility, mobility, and adaptability, from assisting in high-risk scenarios to augmenting industrial processes. Equipped

with sensors, actuators, and AI, they can precisely perceive their surroundings, make decisions, and execute tasks. Humanoids are increasingly employed in healthcare, aiding in patient care and rehabilitation, and they hold promise in addressing labor shortages in industries.<sup>11</sup> Researchers focus on enhancing their cognitive abilities as they evolve, enabling them to comprehend and respond to complex human emotions and social cues. Ethical considerations surrounding their deployment, such as privacy and the potential impact on employment, also accompany their development. Despite these challenges, humanoid robots continue to push the boundaries of what machines can achieve, offering innovative solutions to real-world problems and opening new avenues for human-robot collaboration.<sup>12,13</sup> The forthcoming discussion will delve further into various techniques, shedding more light on the intricacies of humanoid robotics.

- *Characteristics of Humanoid Robot:* Humanoid robots boast striking resemblances to humans, featuring anthropomorphic designs that emulate human anatomy. Their naturalistic motions, a key characteristic, enable fluid and lifelike movements, enhancing their adaptability in various environments. The versatility of humanoid robots extends beyond mere physical resemblance, allowing them to perform a wide range of tasks with agility and precision. An inherent trait is their interactive nature, facilitating user engagement through speech, gestures, and expressions. Furthermore, these robots exhibit collaborative capabilities, seamlessly working alongside humans in tasks that demand teamwork.<sup>14-17</sup> These defining characteristics collectively position humanoid robots as multifaceted entities poised to revolutionize industries and human-robot interactions. Which are shown in Fig. 2.

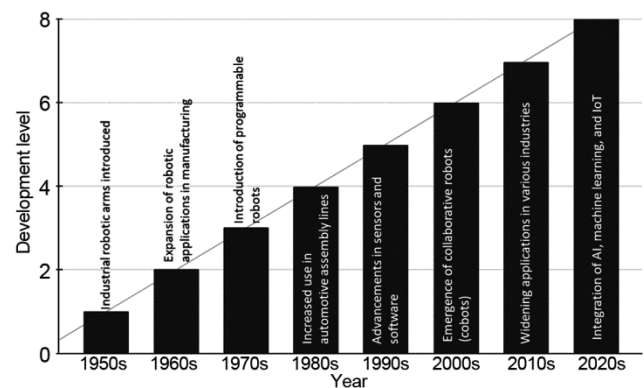


Fig. 1 — Evolution of robotics development over decades

- Sensing and Perception:** Sensing and perception are vital facets of humanoid robots, encompassing various modalities to enhance their interaction with the environment as mentioned in Fig. 3. Vision capabilities empower robots with sight, enabling object recognition and navigation. Auditory sensors equip them with sound perception, facilitating responsiveness to auditory cues.<sup>18</sup> Tactile and force sensors endow robots with a sense of touch, crucial for delicate tasks and safe interactions with objects and humans. Environmental awareness, a critical dimension, involves the integration of sensors to comprehend surroundings, ensuring adaptability to dynamic conditions. This comprehensive sensory suite enables humanoid robots to interpret and respond to their environment, fostering versatility and effectiveness in diverse tasks and scenarios.<sup>19,20</sup>



Fig. 2 — Characteristics of humanoid robot

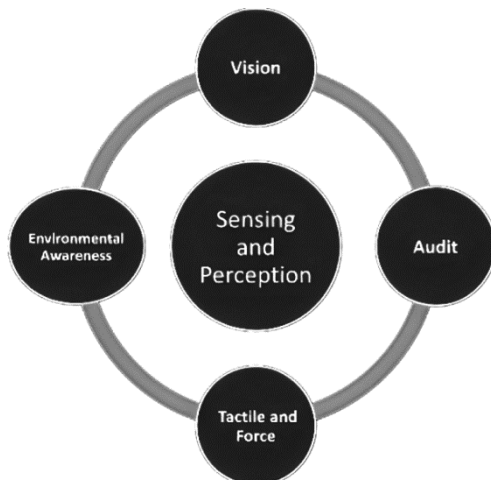


Fig. 3 — Sensing and perception

- Locomotion in Humanoid Robot:** Locomotion in robotics is a dynamic interplay between legged movement, balancing, and stability control, crucial for navigating diverse terrains and environments. Balancing mechanisms ensure the robot maintains stability during motion, preventing falls and enabling agile maneuvers. Stability control algorithms contribute to real-time adjustments, optimizing weight distribution and adapting to changing surfaces.<sup>21</sup> This comprehensive approach to locomotion empowers robots to move effectively, negotiate obstacles, and operate in challenging conditions, extending their applicability across various fields, from search and rescue missions to industrial tasks.<sup>22</sup>
- Human-Robot Interaction:** Human-robot interaction is enriched through multi-faceted communication channels, incorporating speech and natural language, emotional and social intelligence, gesture and facial expressions, and haptic interaction. Speech and natural language capabilities enable robots to comprehend and respond to verbal commands, facilitating seamless communication with humans. Emotional and social intelligence equip robots with an understanding of human emotions and social cues, fostering empathetic interactions.<sup>23–25</sup>

The integration of gestures and facial expressions allows robots to convey information non-verbally, enhancing the subtlety and nuance of communication. Haptic interaction, involving touch and physical feedback, deepens the interactive experience, enabling robots to engage with users on a tactile level.<sup>26,27</sup> Together, these elements form a comprehensive framework for human-robot interaction, enriching communication and collaboration and paving the way for robots to become integral partners in various domains, from healthcare to customer service, as highlighted in Fig. 4.

**Methodology for the Proposed Working Model of Robotic Hand**

The methodology for the operation of the humanoid robotic left arm involves a systematic approach to data acquisition, model implementation, and the utilization of machine learning algorithms. Data acquisition encompasses the integration of sensors such as MPU-6050 and MPU9250, capturing essential physical information from the environment. The MPU-9250 was chosen due to its advanced 9-axis sensor fusion capabilities, combining a 3-axis gyroscope, a 3-axis

accelerometer, and a 3-axis magnetometer. This allows for highly accurate motion tracking and orientation sensing, which are crucial for the precise control of the robotic arm. In contrast, the MPU-6050, which combines only a 3-axis gyroscope and a 3-axis accelerometer, lacks the additional magnetometer, making it less suitable for applications requiring precise orientation in three-dimensional space.

The employed model, particularly relevant to the robot's working, integrates Inverse Kinematics for precise joint parameter calculation, Reinforcement

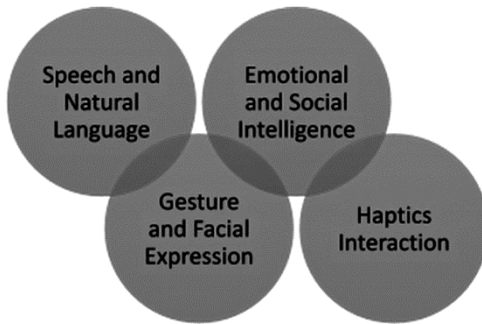


Fig. 4 — Human-robot interaction

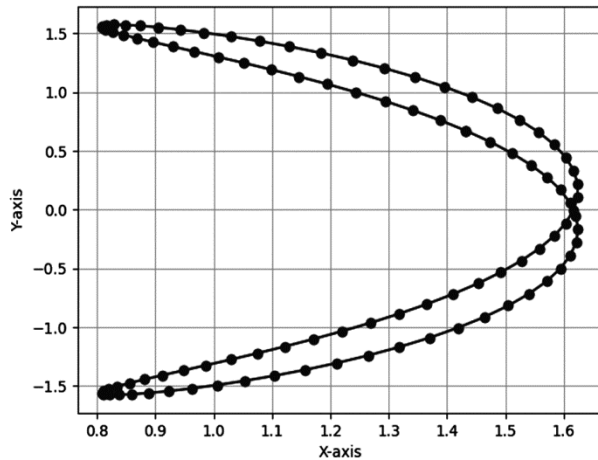


Fig. 5 — 2-DOF robot arm forward kinematics trajectory

Learning for adaptive decision-making in dynamic scenarios, and Deep Learning to process sensory inputs and recognize patterns. The methodology also involves using standard methods to ensure the accuracy and reliability of the experimental setup. These methods include rigorous calibration of sensors to minimize measurement errors and validate kinematic models to ensure that the robotic arm's movements accurately correspond to the desired inputs. Data transmission is facilitated through IoT connectivity, enabling seamless communication between the robotic arm and human joints. This holistic methodology ensures a comprehensive workflow, allowing the robot to operate collaboratively, make informed decisions, and respond dynamically to its surroundings, showcasing a blend of advanced robotics and machine learning.

The units of the X and Y axes in the given plot would be in arbitrary units since the specific lengths of the robot arm segments ( $l_1$  and  $l_2$ ) are defined. The movement pattern and trajectory shape are meaningful regarding the robot arm's configuration. Still, the exact scale is not defined unless the lengths of the robot arm segments are specified in real-world units (e.g., meters), as shown in Fig. 5. The units are relative and depend on the scaling of the robot arm lengths, which are not explicitly provided here.

**Data Acquisition**

The 3D printing of this robotic arm was initiated using the PLA+ material for this project. MPU6050 and MPU9250 sensors are deployed to achieve the desired degree of rotation and movement in the robotic arm.<sup>15</sup> The primary function of the MPU-6050 sensor is to measure the acceleration and angular velocity in 6-directions of freedom. Meanwhile, the MPU-9250 measures acceleration, angular velocity, and magnetometers in 9 degrees of freedom.

Sensor-wise specification is discussed in Table 1 below:

Table 1 — Specification of MPU-6050 and MPU-9250

| Specification                                     | MPU-6050                                                                                         | MPU-9250                                                                                         |
|---------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| Axis                                              | 3 Axes viz., X, Y & Z                                                                            | 3 Axes viz., X, Y & Z                                                                            |
| Accel full scale range (in g)                     | User Configurable; $\pm 2g, \pm 4g, \pm 6g, \pm 8g, \& \pm 16g$                                  | User Configurable $\pm 2g, \pm 4g, \pm 6g, \pm 8g$ & $\pm 16g$                                   |
| Gyroscopic axis                                   | 3Axes viz., X, Y & Z                                                                             | 3 Axes viz., X, Y & Z                                                                            |
| Gyro full scale range (in $^{\circ}/\text{sec}$ ) | User Configurable; $\pm 250^{\circ}, \pm 500^{\circ}, \pm 1000^{\circ}$ , and $\pm 2000^{\circ}$ | User Configurable; $\pm 250^{\circ}, \pm 500^{\circ}, \pm 1000^{\circ}$ , and $\pm 2000^{\circ}$ |
| Communication                                     | Inter-Integrated Circuit communication is configurable to the I2C slave address.                 | 3 Axes viz., X, Y & Z in Magnetometer, with a measurement range of $\pm 4800\mu\text{T}$         |
| Operating voltage                                 | 2.5V–3.5 V                                                                                       | 2.5V–3.5V                                                                                        |
| Temperature sensor                                | Accuracy upto $\pm 1^{\circ}\text{C}$                                                            | Accuracy upto $\pm 1^{\circ}\text{C}$                                                            |

### Mathematical Analysis

This implementation is crucial in enhancing spatial awareness by utilizing the MPU-6050 and MPU-9250 sensor data. By extracting Pitch, Roll, and Yaw angles, the code enables a nuanced understanding of orientation in three-dimensional space. Its versatility makes it invaluable for applications ranging from immersive virtual reality experiences to precise navigation systems, where accurate motion tracking and orientation detection are paramount. Integrating accelerometer and magnetometer data ensures a robust and reliable solution, making this code a cornerstone for projects demanding high-precision spatial information. Below is the code used to implement Pitch, Roll, and Yaw angles using Accelerometer and Magnetometer sensor data from MPU-6050 and MPU-9250 sensors.

$$\begin{aligned} pitch &= \arctan2(\text{accelY}, \sqrt{\text{accelX}^2 + \text{accelZ}^2}) \\ roll &= \arctan2(-\text{accelX}, \sqrt{\text{accelY}^2 + \text{accelZ}^2}) \\ Y_h &= (\text{magY} \cdot \cos(roll)) - (\text{magZ} \cdot \sin(roll)) \\ X_h &= (\text{magX} \cdot \cos(pitch)) + (\text{magY} \cdot \sin(roll) \\ &\quad \cdot \sin(pitch)) + (\text{magZ} \cdot \cos(roll) \\ &\quad \cdot \sin(pitch)) \\ yaw &= \arctan2(Y_h, X_h) \\ roll &= roll \cdot 57.3 \\ pitch &= pitch \cdot 57.3 \\ yaw &= yaw \cdot 57.3 \end{aligned}$$

**Functions:-** Further breaking down each part of the formula and explaining its purpose is discussed below:

#### Pitch Calculation

The pitch is the angle around the x-axis and is calculated using the arctangent function. It is the angle between the y-axis and the projection of the vector onto the x-z plane.

$$pitch = \arctan2(\text{accelY}, \sqrt{\text{accelX}^2 + \text{accelZ}^2})$$

#### Roll Calculation

The roll is the angle around the y-axis, calculated similarly to pitch. It is the angle between the x-axis and the projection of the vector onto the y-z plane.

$$roll = \arctan2(-\text{accelX}, \sqrt{\text{accelY}^2 + \text{accelZ}^2})$$

#### $Y_h$ Calculation

$Y_h$  is the horizontal component of the magnetic field in the y-z plane after correcting for roll.

$$Y_h = (\text{magY} \cdot \cos(roll)) - (\text{magZ} \cdot \sin(roll))$$

#### $X_h$ Calculation

$X_h$  is the horizontal component of the magnetic field in the x-y plane after correcting for pitch and roll.

$$\begin{aligned} X_h &= (\text{magX} \cdot \cos(pitch)) + (\text{magY} \cdot \sin(roll) \\ &\quad \cdot \sin(pitch)) + (\text{magZ} \cdot \cos(roll) \\ &\quad \cdot \sin(pitch)) \end{aligned}$$

#### Yaw Calculation

The yaw is the angle around the z-axis. It is the angle between the projection of the magnetic vector onto the x-y plane and the x-axis.

$$yaw = \arctan2(Y_h, X_h)$$

Further, the calculated pitch, roll, and yaw angles are converted from radians to degrees.

$$\begin{aligned} roll &= roll \cdot 57.3 \\ pitch &= pitch \cdot 57.3 \\ yaw &= yaw \cdot 57.3 \end{aligned}$$

In summary, these formulas are used for sensor fusion, specifically for calculating pitch, roll, and yaw angles from accelerometer and magnetometer measurements, taking into account the orientation of the sensor. The resulting angles are often used in applications such as orientation tracking in robotics or mobile devices.

#### Employed Model

The implementation process was initiated with the design phase, followed by a thorough evaluation of the software and hardware requirements in accordance with the design specifications. Once all components were in place, separate integration processes for the software and hardware systems were executed. A rigorous verification process was conducted after successful implementation to ensure the systems operated as intended. Upon completing the evaluation and readiness of personal equipment, the final step involved the comprehensive integration of software and hardware systems into a unified operational framework.

To facilitate a clear and structured implementation, a block diagram outlining the entire working procedure was developed, as depicted in Fig. 6. In this diagram, the flow of data from the gyroscope (input) through the Arduino Uno and ESP32 (process) to the servo motor (output) is illustrated. The transmitter end comprises a gyroscope interfacing with an Arduino Uno, where the motion data is processed. The processed data is then transmitted to an ESP32, serving as the central processing unit. On the receiver

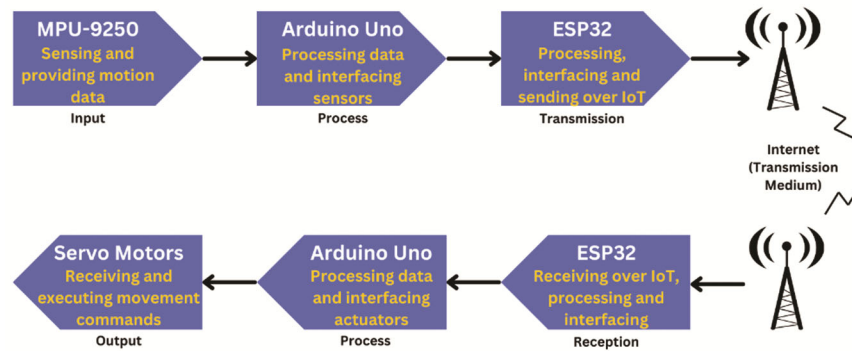


Fig. 6 — Block diagram of system workflow

end, another Arduino Uno receives the data from the ESP32 and controls the servo motor, ensuring accurate and coordinated movements.

In Fig. 7, the detailed schematic of the connections required for optimal performance of the robotic hand is shown. This figure illustrates the connections between the ESP32, TCA9548A multiplexer, and multiple MPU-9250 sensors, where Arduino Uno is not used as the data from various sensors are collected by TCA9548A and sent to ESP32 for further process of transmission directly, using IoT. The ESP32 processes signals from the MPU-9250 sensors via the TCA9548A, which acts as a communication interface. The servo motor, equipped with built-in Wi-Fi communication, receives these processed signals and commands the DC motor to execute precise movements. This setup ensures that the robotic hand can accurately mimic the motions of the human hand by translating sensor data into actuator commands.

The MPU-9250 sensor functions as the central component for motion control in the robotic hand, with the robot's movements being managed through this sensor. The MPU-9250, acting as the controller, interfaces with the ESP32 servo driver and TCA9548A multiplexer. Communication between the robot's motion control and the hand's movements is facilitated by the TCA9548A. The ESP32, functioning as a servo driver, processes the signals received from the MPU-9250 and controls the servo motors accordingly. This methodological approach highlights the integration of advanced sensor technology, robust communication interfaces, and precise actuator control to achieve high-performance, coordinated movements in robotic applications.

**Considered Machine Learning Algorithms**

In this paper, the integration of machine learning algorithms plays a pivotal role in enhancing the

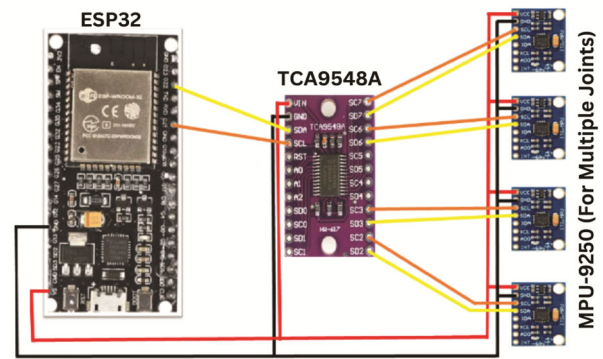


Fig. 7 — Connection schematic for optimal robot hand performance

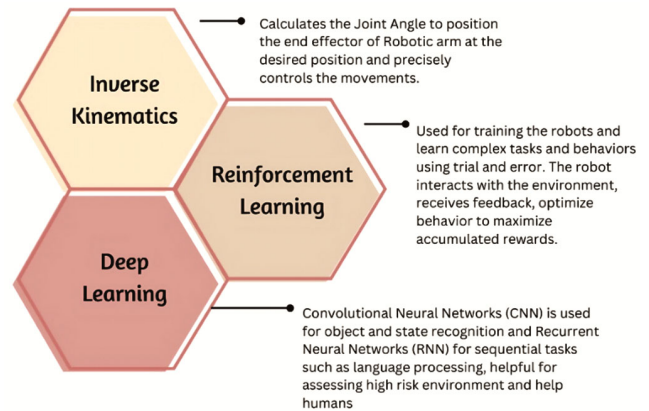


Fig. 8 — Machine learning algorithms

capabilities of the humanoid robotic left arm. One key algorithm employed is Inverse Kinematics, which calculates the joint parameters required to achieve a desired end effect or position, as discussed in Fig. 8. This algorithm enables precise control of the robot's movements, particularly in collaborative tasks with human joints, ensuring fluid and accurate motions.<sup>20,27</sup> The utilization of Reinforcement Learning further augments the robot's adaptability in high-risk environments. Through trial and error, the robot learns optimal actions based on environmental feedback,

refining its decision-making process and enhancing overall performance during complex operations.

Reinforcement Learning (RL)<sup>3,20</sup> is a powerful machine learning paradigm suitable for training agents to make decisions in an environment through trial and error. In humanoid robotic arms, RL could play a crucial role in training the robotic arm to perform tasks in high-risk situations in collaboration with human movements. The methodology for the reinforcement learning is discussed below,

- *Training for Coordination:* RL can be used to train the robotic arm to coordinate its movements with the human joints. The algorithm can learn from the movements of a human arm in various situations and adapt its actions to work collaboratively in high-risk environments.
- *Adaptive Responses:* In high-risk scenarios, the environment may change dynamically. RL allows the robotic arm to adapt its responses based on feedback. For example, if the arm senses a deviation or disturbance, the RL algorithm can adjust the control signals to maintain stability.
- *Learning from Human Demonstrations:* RL can incorporate learning from human demonstrations. By observing and imitating human movements, the robotic arm can acquire practical skills and strategies in high-risk situations, enhancing its ability to assist in emergencies.
- *Real-time Decision Making:* RL algorithms can facilitate real-time decision-making for the robotic arm. In unpredictable or hazardous scenarios, the ability to make adaptive decisions based on the current environment is crucial. RL enables the robotic arm to learn and optimize its actions on the fly.
- *Risk Mitigation:* RL can contribute to risk mitigation by allowing the robotic arm to learn safe and efficient strategies. Through a reward-based system, the algorithm can guide the arm to perform actions that minimize the risk of collateral damage and enhance the safety of emergency service crews.

Reinforcement learning is a potential candidate for training and optimizing the humanoid robotic right arm to operate effectively in collaboration with human joints, especially in high-risk environments, which is done for designing this model.

Deep Learning constitutes another essential facet, leveraging neural networks to empower the robot with advanced perception and decision-making abilities. Integrating deep learning algorithms allows the robot

to process complex sensory inputs, recognize patterns, and make informed decisions, contributing to its efficiency in responding to environmental changes. The synergistic application of these machine-learning algorithms reflects a sophisticated approach, enabling the humanoid robotic left arm to navigate intricate tasks collaboratively and autonomously, marking a significant advancement in human-robot interaction and robotic capabilities.

#### Data Transmission

For data transmission, the preceding steps involve initial data acquisition from IMU sensors and angular and linear motion data capture. The captured measurements are then transmitted to the ESP32 node MCU. From there, data is relayed to the Arduino UNO via Universal Asynchronous Receiver and Transmitter (UART) communication for further processing and control of the robotic arm.

UART is a serial communication protocol to transmit and receive data between electronic devices. The robotic arm uses an ESP-32 Node MCU, a development board with an ESP-32 microcontroller, and its primary function is enhancing wireless capabilities using Wi-Fi and Bluetooth. Generally, it is suitable for IoT projects and Prototyping. ESP32 is compatible with Arduino, which implies that it can be programmed using Arduino IDE, having pertinent built-in flash memory to store program code and data.

The data is then sent from the ESP-32 MCU node to the Server driver using TCDA 9548A-I2C multiplexer, allowing it to communicate with up to 8 devices via wireless communication protocols shown in Fig. 9. Four Servo Motors are installed in the humanoid robotic hand to achieve various degrees of motion; hence, 4 degrees of freedom are used in one hand of the robot.

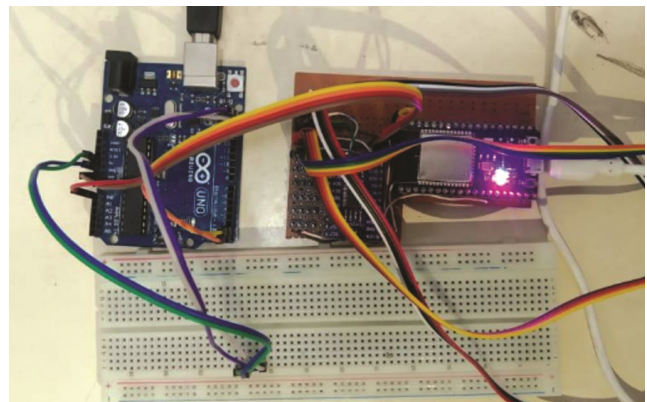


Fig. 9 — Data transmission from Arduino UNO to ESP-32

## Results and Discussion

Our experiments demonstrated how the integration of hardware components, including motors, servo drivers, and IMU sensors, led to the achievement of precise and coordinated movements of a robotic arm. This integration played a crucial role in validating our hypothesis, emphasizing the effectiveness of combining computational intelligence with physical machinery. Notably, movements were smoothly executed by the robotic hand, showcasing this integrated approach's success.

Several significant findings were yielded by our investigation into humanoid-robot collaboration, particularly in high-risk environments:

- Significantly enhanced movement precision and coordination were achieved through the seamless integration of hardware components. This integration enabled the robotic system to adapt to changing conditions dynamically, showcasing a level of sophistication previously unattained in humanoid robotics.
- The understanding of effective collaboration between humanoid robots and humans, especially in challenging contexts, was advanced by our research. Insights into potential applications and associated challenges were gained by dissecting the nuances of this collaboration, thereby informing future deployment strategies.
- The emergence of IoT technologies as a foundational element of our experimentation was observed. A robust communication framework was established between human operators and robotic arms, facilitating synchronized movements and

augmenting overall operational efficiency and effectiveness.

- A critical aspect of our experimentation was the strategic deployment of sensors, notably the MPU-9250. These sensors exhibited remarkable responsiveness, enabling rapid detection of environmental changes and deviations. This dynamic adaptation capability was instrumental in ensuring the agility and adaptability of the humanoid robot, particularly in navigating complex and unpredictable terrains.

A significant step forward in the practical realization of collaborative and assistive robotics is represented in our research. By unraveling the complexities of humanoid robot collaboration and leveraging cutting-edge technologies, the groundwork for future advancements in this burgeoning field has been laid. The robotic arm was seamlessly communicated with the human arm, integrated with sensors, through IoT, enabling successful and coordinated movements in all directions – up, down, right, and left, as demonstrated in Figs. 10 to 12.

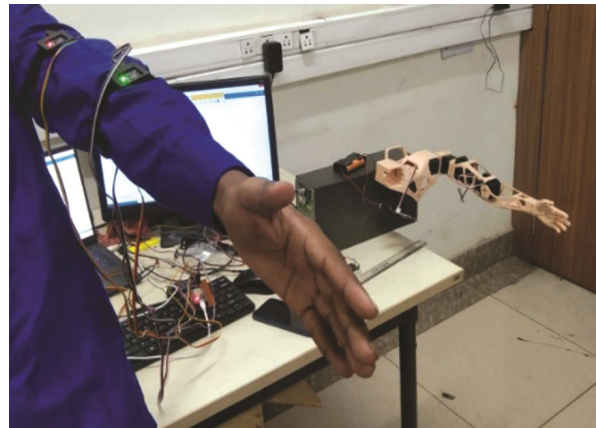


Fig. 11 — Left hand up motion



Fig. 10 — Left hand down motion

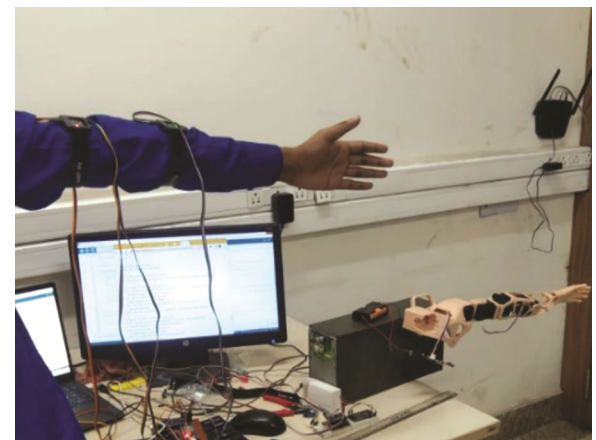


Fig. 12 — Left hand side motion

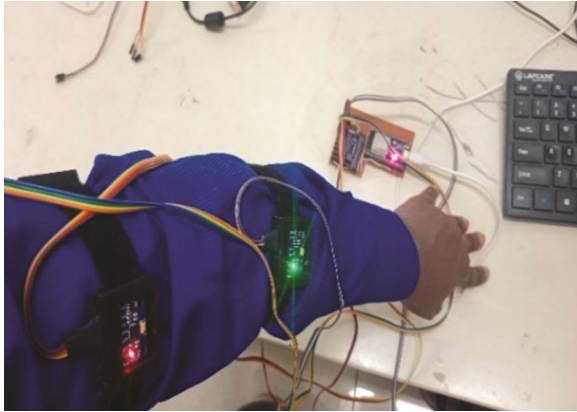


Fig. 13 — Sensor placement in the hand

Additionally, the sensor placement in the human hand, which sends data to the collaborative robot through IoT, is illustrated in Fig. 13.

In our research, we stressed how crucial human thinking is. Nothing can replace the human brain. But we showed that using robots controlled by people from safe places during dangerous situations makes things safer. These robots can handle heavy loads and go into areas with hazardous gases, protecting human lives better.

### Conclusions

In conclusion, this research has successfully enhanced the precision and responsiveness of a robotic arm in hazardous environments by integrating IoT technology with sensor data and mathematical calculations. The findings highlight significant potential for applications in emergency response and other critical operations requiring precise and reliable robotic assistance. However, limitations were encountered, such as high computational demands and challenges in real-time data processing. Future research should optimize these calculations to reduce computational requirements and improve system robustness in diverse and unpredictable conditions. Further exploration into enhancing the human-robot interaction interface is recommended to ensure seamless and intuitive operation. Despite these challenges, the study demonstrates a promising direction for improving operational safety and efficiency in high-risk scenarios through the development of IoT-enabled robotic systems.

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