

Hand Gesture Control Wireless Bluetooth Robotic Arm With wheels

Abhinaw Kumar Singh^a, Ajyant Prakash Singh^b, Abhay Pratap Singh^c, Akash Chaurasiya^d, Manob Hazarika^e

^{a,b} Department of Electrical Engineering, KIPM College of Engineering and Technology, U.P., India

^c Assistant Professor, Department of Electrical Engineering, KIPM College of Engineering and Technology, U.P., India

abhinawkumar309@gmail.com, ajanikh4@gmail.com, abhayptsingh60@gmail.com,

akashchaurasiya0104@gmail.com, manob.ee@kipm.edu.in,



KEYWORD

Robotic, Hand Gesture Control, Artificial Intelligence, Face Recognition, Deep Learning,

ABSTRACT

This paper presents the design and development of a hand gesture controlled wireless robotic arm integrated with a mobile wheeled platform using Bluetooth communication. The system is designed to provide an intuitive and user-friendly method for controlling robotic movements by translating human hand gestures into corresponding mechanical actions. Hand gestures are captured using sensor-based input devices mounted on a glove, and the sensed data is processed by a microcontroller to generate control commands. These commands are transmitted wirelessly to the robotic unit through a Bluetooth module, enabling real-time operation without physical connections. The robotic system consists of a multi-degree-of-freedom robotic arm mounted on a wheeled base, allowing both object manipulation and mobility. The arm is driven by servo motors to perform actions such as gripping, lifting, and placing objects, while DC motors are used to control the movement of the wheels. The control logic ensures smooth and accurate response to user gestures with minimal delay. Experimental testing demonstrates reliable gesture recognition, stable wireless communication, and satisfactory system response time, making the system suitable for small-scale industrial automation, assistive robotics, and educational applications. The proposed system reduces the complexity of traditional control methods and improves human-robot interaction by providing natural and efficient control. Its low cost, ease of implementation, and flexible design make it a practical solution for applications requiring remote and contactless robotic control.

1 Introduction

The rise of robotics and automation has revolutionized the way humans interact with machines across industrial, medical, and domestic domains. With the convergence of embedded systems, wireless communication, and artificial intelligence, robotic systems have evolved from rigid, pre-programmed machines into flexible, intelligent systems capable of performing a wide range of tasks autonomously or semi-autonomously [1]. Among various approaches to human-machine interaction (HMI), gesture-controlled interfaces have emerged as one of the most promising paradigms due to their naturalness, intuitiveness, and adaptability [2]. Traditional robotic systems rely heavily on wired interfaces, joysticks, or complex software programming to control robotic actuators. While such systems are precise, they often lack flexibility and limit the operator's mobility. In contrast, hand gesture recognition-based robotic systems allow users to control robotic movements through simple gestures, eliminating the need for cumbersome input devices and providing a more direct, natural form of communication [3].

The concept of integrating gesture recognition with a wireless robotic arm mounted on a mobile platform combines two key domains: motion sensing and robotics control. This integration facilitates a system where human gestures can command both arm movements and platform navigation simultaneously. The system proposed in this work — “Hand Gesture Controlled Wireless Bluetooth Robotic Arm with Wheels” — leverages Bluetooth wireless

Corresponding Author: Abhinaw Kumar Singh, Scholar, Department of Electrical Engineering, KIPM College of Engineering and Technology, U.P., India
Email: abhinawkumar309@gmail.com

technology to enable real-time communication between the gesture recognition unit and the robotic base. Bluetooth communication provides a balance between energy efficiency, range, and data throughput suitable for short-distance wireless control applications [4]. Compared with Wi-Fi, Bluetooth consumes less power and has simpler pairing mechanisms, making it ideal for battery-operated embedded systems such as robotic arms [5]. Gesture control has been extensively studied in the context of human–robot interaction (HRI). The primary advantage of gesture-based control systems is their intuitive operation, which does not require prior programming knowledge or physical control panels [6]. Users can control robotic actions through gestures captured by sensors such as accelerometers, gyroscopes, and flex sensors, which measure hand orientation, tilt, and bending, respectively [7]. The gesture data are processed by a microcontroller, often an Arduino or ESP32, that interprets sensor inputs as specific movement commands for the robot. This process involves converting analog sensor values into digital control signals corresponding to various motor actions such as forward, backward, grip, release, or rotation [8]. Applications of gesture-controlled robotics span across industries. In manufacturing, such systems enable workers to manipulate robotic arms remotely for assembly, welding, or packaging tasks [9]. In healthcare, gesture-controlled robotic arms are used for assisting physically challenged individuals or performing surgical procedures where precision and remote control are vital [10]. In hazardous environments, robots controlled through hand gestures can perform operations in areas with high radiation, toxic gases, or extreme temperatures, ensuring human safety [11]. Despite the progress made in gesture-controlled robotics, there are persistent challenges in achieving real-time accuracy, low latency, and reliable communication between the control and robotic units [12]. Traditional wired systems limit mobility, while wireless systems often face issues related to interference, signal loss, or synchronization delays. Moreover, many existing models either focus solely on stationary robotic arms or on mobile robots, without combining mobility and manipulative capability into a single integrated system [13].

Another limitation lies in gesture recognition precision. Inaccurate gesture detection or improper mapping between gesture and action can lead to errors in robotic control, potentially damaging the system or the objects being manipulated [14]. To address these challenges, Bluetooth-based communication, real-time gesture sensing, and multi-axis control are used to ensure seamless operation between the user and robot. The Hand Gesture Controlled Wireless Bluetooth Robotic Arm with Wheels is designed to achieve three core objectives the first is gesture-based control using sensors that capture hand motion data and the second one is wireless communication using a Bluetooth module (e.g., HC-05 or HC-06) to transmit commands and the last one is robotic arm integration on a mobile platform equipped with DC or servo motors for movement. The project consists of two main units where the transmitter has gesture recognition glove equipped with MEMS (Micro-Electro-Mechanical Systems) sensors such as accelerometers and gyroscopes. When the user moves their hand in different directions, the sensor readings change, and these signals are processed by a microcontroller Arduino UNO. The microcontroller encodes the gestures into specific command packets and transmits them wirelessly through the Bluetooth module. The receiver side contains a Bluetooth receiver module, a microcontroller, and motor driver circuits connected to the robotic arm and wheel motors. Based on received commands, the robotic arm performs specific actions such as gripping, rotating, or lifting, while the wheeled platform moves forward, backward, or turns accordingly. This dual-component design ensures smooth simultaneous control of locomotion and manipulation [15]. The gesture recognition process begins with sensor calibration and data acquisition. Each gesture corresponds to a specific range of sensor values, which are mapped to predefined robotic commands. For example, a forward tilt of the hand may correspond to moving the robot forward, while a rotation of the wrist could initiate the robotic arm's gripper movement [16]. The communication process relies on serial data transmission between the microcontrollers of the transmitter and receiver modules using Bluetooth serial communication protocol. The HC-05 Bluetooth module operates at a baud rate of 9600 bps, sufficient for transmitting command data in real-time without noticeable delay [17]. At the receiver end, the data are decoded and interpreted by the microcontroller, which activates the corresponding actuators. The robotic arm uses servo motors for precise angular control and DC motors for wheel locomotion. For wireless control Bluetooth are used to eliminates the need for physical cables, allowing for unrestricted operator movement [18]. This project uses low-cost components such as Arduino, Bluetooth modules, and sensors, making it ideal for educational and prototyping applications [19]. The gesture-based interface enables control without specialized training and the remote operation allows users to perform tasks in hazardous environments safely. The system architecture can be upgraded with IoT connectivity or AI-based gesture recognition for enhanced performance [20].

Bharadwaj, Gawai, and Gulhane (2025) developed a gesture-controlled robotic car learning algorithms machine to improve gesture recognition accuracy through sensor data fusion. Their system used the HC-05 Bluetooth module for

wireless communication and achieved low latency in response [9]. Similarly, Zhang and Liu (2025) developed a Bluetooth-controlled manipulator using an adaptive control algorithm for real-time robotic arm coordination [10]. Their work demonstrated that integrating PID control loops with gesture input signals significantly improves accuracy and smoothness of motion. Earlier, Gupta et al. (2021) implemented a hand gesture-controlled robotic arm using MEMS sensors, focusing on low-power microcontrollers to achieve efficient data processing [3]. Rahman and Kim (2021) provided a comprehensive review of gesture recognition systems in robotics, highlighting the potential of inertial sensors and neural networks for gesture classification [2].

In recent the integration of Internet of Things (IoT) features, enabling cloud-based monitoring of robotic systems [21]. Furthermore, research by Dutta and Mitra (2021) explored assistive robotics applications, where gesture-controlled arms enhanced mobility for disabled individuals [8]. In Industrial Automation the gesture-controlled robots can handle assembly lines, packaging, and quality inspections where flexibility and precision are critical [22] and in medical field this robotics arms can help patients regain autonomy in daily activities through intuitive control [23]. It uses for search and rescue operations where its can navigate in hazardous environments and manipulate objects remotely under human supervision [24]. It gives students a hands-on environment for learning about embedded systems, robotics, and control theory [25]. Future enhancements could integrate AI-based gesture recognition using convolutional neural networks (CNNs), computer vision, and sensor fusion to improve accuracy and robustness under different lighting or environmental conditions. Moreover, integrating IoT connectivity could allow the system to be monitored or controlled remotely over the internet, expanding its operational range beyond Bluetooth limitations [26].

2 Literature Review

The literature review show the technological advancements, and existing robotic systems related to hand gesture control, robotic arms, wireless communication, and automation. This review helps in understanding the evolution of gesture-controlled robotic systems and identifies the limitations of existing approaches that motivate the present research. Gesture-controlled robotics has emerged as an important area of human-machine interaction, enabling natural and intuitive control of machines without physical contact [1], [2]. Over the past two decades, significant research has been conducted on robotic arm design, gesture recognition techniques, and wireless control mechanisms. Several studies have focused on accelerometer-based gesture detection and Arduino-based robotic control due to their simplicity, low cost, and real-time performance [3], [13], [16]. Bluetooth communication has been widely adopted for short-range wireless control of robotic systems because of its low power consumption and ease of implementation [4], [5]. Recent literature also highlights the application of gesture-controlled robots in industrial automation, assistive robotics, and educational platforms, demonstrating the growing importance of this technology [6], [8], [25]. However, many existing systems suffer from limitations such as complex hardware design, high cost, limited mobility, or lack of real-time responsiveness. Therefore, there is a need for a simple, cost-effective, and reliable gesture-controlled robotic system that integrates robotic arm manipulation with mobile base movement. This literature review discusses existing robotic arm designs, gesture detection methods, wireless communication techniques, and their limitations to establish the foundation for the proposed work.

3 Evolution of Robotic Arms

Robotic arms were first introduced in the early 1960s, mainly for industrial automation applications. The first programmable industrial manipulator, known as Unimate, was installed in a General Motors manufacturing plant in 1961, marking the beginning of automated robotic manipulation in industry [6], [22]. Early robotic arms were purely mechanical in nature and relied on wired control systems, switches, and basic control algorithms to perform repetitive tasks. With the advancement of microcontrollers, sensors, and embedded systems, robotic arm technology has evolved significantly over time. Control methods shifted from wired connections to wireless communication, enabling greater flexibility and ease of operation [4], [5]. Fixed-base robotic arms were gradually extended to mobile robotic platforms, allowing robots to operate in dynamic environments [19]. Similarly, traditional mechanical grippers were replaced by servo-controlled grippers, providing improved precision, controllability, and adaptability in manipulation tasks [30]. Modern robotic arms integrate with high-precision sensors, advanced microcontrollers, and, in some cases, artificial intelligence algorithms to perform complex and adaptive tasks in industrial, medical, assistive, and educational

applications [8], [11]. This continuous evolution has led to the development of more intelligent, flexible, and user-friendly robotic arm systems.

4 Gesture Recognition

Gesture recognition is the process of interpreting human hand or body movements and translating them into control commands for machines. In robotic systems, gesture recognition enables natural and seamlessly human-machine interaction, reducing the need for physical interfaces such as switches or joysticks [2], [7]. Based on sensors, gesture recognition techniques in robotics are classified into vision-based and sensor-based methods. Vision-based gesture recognition systems use cameras along with image-processing and computer vision algorithms to detect and interpret gestures. These systems can achieve high accuracy and are capable of tracking complex and continuous hand movements [12], [27]. However, vision-based approaches have several limitations. They are generally expensive, require high computational power, and depend heavily on environmental conditions such as lighting and background. Due to these constraints, vision-based systems are often unsuitable for portable, low-cost, and real-time robotic applications [7]. Sensor-based gesture recognition systems use wearable sensors such as accelerometers, gyroscopes, and flex sensors to detect hand movements. These systems are low-cost, portable, and easy to interface with microcontrollers such as Arduino. Sensor-based methods are independent of lighting conditions and offer reliable performance in real-time applications [13], [16]. Although they have limitations in detecting highly complex gestures, they are well suited for practical robotic control due to their simplicity and efficiency. Accelerometer-based gesture recognition is selected for this project that provides an effective balance between accuracy, simplicity, and cost. The use of an accelerometer enables reliable detection of hand movements while maintaining low hardware complexity and real-time responsiveness, making it suitable for gesture-controlled robotic arm and mobile base applications [5], [16].

5 Accelerometer

Accelerometer-based gesture recognition systems use sensors such as ADXL335 or ADXL345 to detect motion and orientation along the X, Y, and Z axes. These sensors convert physical hand movements into electrical signals, which can be processed by a microcontroller to generate control commands for robotic systems. Zhenyu *et al.* (2010) developed a gesture-controlled wheelchair using a three-axis accelerometer. Their work demonstrated that tilt-based gesture control can be effectively used for mobility applications, especially for assisting physically challenged users, proving the feasibility of accelerometer-based control for real-time navigation [31]. J. Liu *et al.* (2012) designed a robotic arm controlled using wrist motions detected by an accelerometer. Their study reported improved accuracy in pick-and-place tasks, highlighting the suitability of accelerometer-based gesture recognition for precise robotic arm manipulation [32]. H. Kim and J. Park (2015) show a hand-motion controlled industrial robotic arm using a combination of accelerometers and gyroscopes. Their system achieved a response time of less than 100 ms, demonstrating fast and reliable real-time performance suitable for industrial environments [33]. This shows that accelerometer-based gesture recognition systems are reliable, responsive, and well suited for real-time robotic control applications, particularly in low-cost and portable robotic systems.

5.1 Bluetooth Communication

Bluetooth is a widely used short-range wireless communication technology that is commonly applied in robotic systems for control and data transmission. Bluetooth modules such as HC-05 and HC-06 are especially popular in DIY and academic robotic projects due to their easy interfacing with Arduino microcontrollers, low implementation cost, reliable communication range of up to 10 meters, and support for simple serial communication using the UART protocol. Hassan *et al.* [29] demonstrated that Bluetooth 5.3's able to handle multi-robot coordination with improved bandwidth and lower latency. Together, these works validate the selection of Bluetooth for wireless communication in this study's robotic arm. R. Gupta and A. Sharma (2016) developed a robot car controlled by a smartphone using Bluetooth communication. Their system demonstrated high stability and low latency, indicating that Bluetooth is suitable for real-time robotic control applications where quick response is required [34]. Mohammad Faisal *et al.* (2018) show the Bluetooth communication is used to control robotic arms operating in hazardous environments. This

show that bluetooth provides reliable and secure short-range communication for industrial robotic applications, especially where wired control is unsafe or impractical [35].

5.2 Servo Motor

Servo motors are widely used in robotic arm systems because they provide high precision, accurate angular positioning, and smooth rotational motion. Due to their built-in feedback mechanism, servo motors allow precise control of joint angles, making them suitable for robotic applications that require controlled and repeatable movements such as arm joints, wrists, and grippers. K. Singh and P. Verma (2017) presented the design and implementation of a four-degree-of-freedom (4-DOF) robotic arm driven by servo motors. Their study highlighted that servo motors provide optimal torque and positioning accuracy for lightweight robotic arms, making them effective for educational and prototype-level robotic systems [36]. J. Park *et al.* (2014) proposed a dynamic control approach for robotic arms using PID-controlled servo motors in medical applications. Their work demonstrated improved stability, smooth motion, and accurate positioning of robotic joints, validating the effectiveness of servo motors in precision-critical tasks [37]. This shows that the servo motors provide better controlling to the robotic arm joints, wrist movement, and gripper operation, ensuring precise, smooth, and reliable arm manipulation.

5.3 DC Motors

Wheeled mobile robots play an important role in modern automation and robotic applications due to their simplicity, flexibility, and ease of control. DC motors are commonly used in mobile robotic platforms because they offer simple control mechanisms, high torque output, and low power consumption. These characteristics make DC motors suitable for driving wheeled robots in both indoor and outdoor environments. A. A. Shukla *et al.* (2019) developed a mobile robot platform using DC motors driven by an L298N motor driver. Their design demonstrated reliable forward, backward, left, and right movements, confirming the effectiveness of DC motor–wheel assemblies for basic navigation and mobility tasks [38]. A. Kumar *et al.* (2020) implemented DC motors in a multi-purpose mobile robot integrated with obstacle detection capabilities. Their study showed that DC motor-based mobile robots can achieve stable movement while supporting additional sensing and control functionalities [39]. This shows that DC motor and wheel assemblies are well suited for mobile robotic bases, providing reliable motion control, simplicity in design, and efficient performance. Therefore, DC motors are used to enable smooth and controlled movement of the robotic platform.

The gesture-controlled robotic systems do only a limited number of works have attempted to integrate gesture control, robotic arm manipulation, and mobile platforms into a single unified system. Most existing studies focus on either robotic arm control or mobile robot navigation, but not both simultaneously. Ortega and Silva [28] further explored machine learning integration for gesture recognition and robotic arm synchronization, highlighting potential for adaptive performance. The current research expands on these works by merging all components gesture sensing, Bluetooth communication, servo-driven arm motion, and DC motor-based locomotion into a single unified robotic platform. S. Rathod and M. Patel (2018) developed a gesture-controlled pick-and-place robotic system that was capable of object manipulation using hand gestures. However, their system lacked mobility, as the robotic arm was mounted on a fixed base, limiting its operational flexibility [40]. K. Harish and M. Reddy (2020) show that a gesture-controlled robotic vehicle that could move based on hand gestures. Although their system demonstrated effective gesture-based navigation, it did not include a robotic arm for manipulation tasks, thereby restricting its functionality to motion control only [41]. This shows that gesture-based control, wireless Bluetooth communication, a robotic arm, and a mobile wheeled platform into a single system. This combined approach enables both robotic manipulation and mobility using intuitive hand gestures, providing a more versatile and practical robotic solution compared to existing systems.

6 Methodology

The methodology shows the designing and developing of the hand gesture–controlled wireless Bluetooth robotic arm with wheels. The methodology covers hardware and software design, system architecture, working principle, block diagram explanation, signal flow, control algorithm, and implementation procedure. This ensures that the robotic

system performs real-time gesture interpretation, reliable wireless communication, accurate robotic arm actuation, and smooth wheeled mobility. The system architecture is divided into two major sections, the transmitter section and the receiver section. The transmitter section, also referred to as the gesture control unit, is worn on the user's hand. It detects hand movements using an accelerometer, processes the sensor values through an Arduino microcontroller, and transmits the corresponding control commands wirelessly using a Bluetooth module. The receiver section consists of the robotic arm integrated with a mobile base. It receives the gesture commands through Bluetooth communication and interprets them using an Arduino controller. Servo motors are used to rotate the joints of the robotic arm, while DC motors drive the robot wheels. A motor driver is employed to control the direction and movement of the motors. Both the transmitter and receiver sections communicate wirelessly in real time, enabling smooth and responsive gesture-based robotic motion.

6.1 Block Diagram

The block diagram represents the overall architecture and signal flow of the hand gesture controlled wireless Bluetooth robotic arm with a mobile base. The system is divided into two main parts, the transmitter section and the receiver section, which communicate with each other through wireless Bluetooth communication.

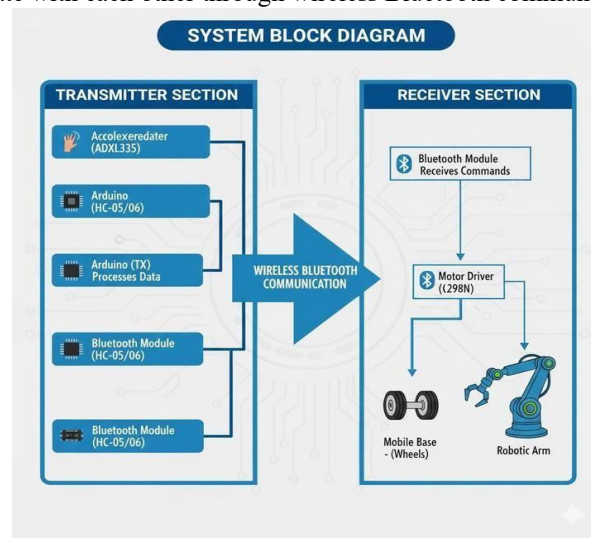


Fig 4.1: Block Diagram Hand Gesture Controlled Wireless Bluetooth Robotic Arm with Wheels

In the transmitter section, an accelerometer (ADXL335) is used to detect hand gestures. The accelerometer senses hand movement and tilt along the X, Y, and Z axes and converts these movements into corresponding analog signals. These signals are sent to the Arduino microcontroller, where the sensor data are processed and converted into predefined control commands based on gesture direction and threshold values. After processing, the generated commands are transmitted wirelessly using a Bluetooth module (HC-05/HC-06). This unit is worn on the user's hand and acts as the gesture control interface. Wireless Bluetooth communication forms the link between the transmitter and receiver sections. The processed gesture commands are transmitted in real time from the transmitter Bluetooth module to the receiver Bluetooth module, enabling fast and reliable data transfer without physical connections. In the receiver section, the Bluetooth module receives the gesture commands and forwards them to the Arduino microcontroller. The Arduino interprets these commands and controls the actuators accordingly. A motor driver (L298N) is used to amplify the control signals and drive the DC motors connected to the mobile base, allowing the robot to move forward, backward, left, or right. At the same time, servo motors are used to control the robotic arm, enabling joint movements such as base rotation, arm lifting, and gripper operation. Thus, the block diagram illustrates how hand gestures are sensed, processed, transmitted wirelessly, and finally converted into coordinated movement of both the robotic arm and the wheeled mobile base, ensuring smooth and real-time gesture-based robotic control[3][13][17].

6.2 Working Principle

The working principle of this system is based on converting hand movements into sensor data, transmitting the processed data wirelessly, and finally converting the received commands into robotic motion. Hand gestures are detected using an accelerometer, which senses the tilt and movement of the user's hand along the X, Y, and Z axes. Different hand orientations correspond to specific robotic actions, such as right and left tilting for directional movement, forward and backward tilting for navigation, raising or lowering the hand for arm lifting and lowering, and twisting motions for gripper opening and closing. The analog output signals generated by the accelerometer are read by the Arduino microcontroller. These raw sensor values are processed and mapped into digital control commands using predefined threshold levels. For example, when the X-axis value exceeds a specified threshold, a corresponding directional command is generated. This processing ensures accurate interpretation of hand gestures and reduces the effect of noise in sensor data. After processing, the generated commands are transmitted wirelessly from the transmitter unit to the receiver unit using Bluetooth modules such as HC-05 or HC-06. The receiver-side Bluetooth module receives the transmitted data and forwards it to the Arduino microcontroller through the serial communication interface. The Arduino then interprets the received commands and controls the actuators accordingly. For robotic arm operation, the Arduino drives multiple servo motors that control the base rotation, shoulder joint, elbow joint, wrist joint, and gripper movement. Simultaneously, DC motors are used to drive the wheels of the mobile base. A motor driver, such as L298N or L293D, is employed to control the direction and speed of the DC motors. For instance, when a forward command is received, both motors rotate in the forward direction, enabling linear motion of the robot. This sequential process enables complete gesture-based control of the robotic arm and mobile platform without the need for physical switches or manual input devices.

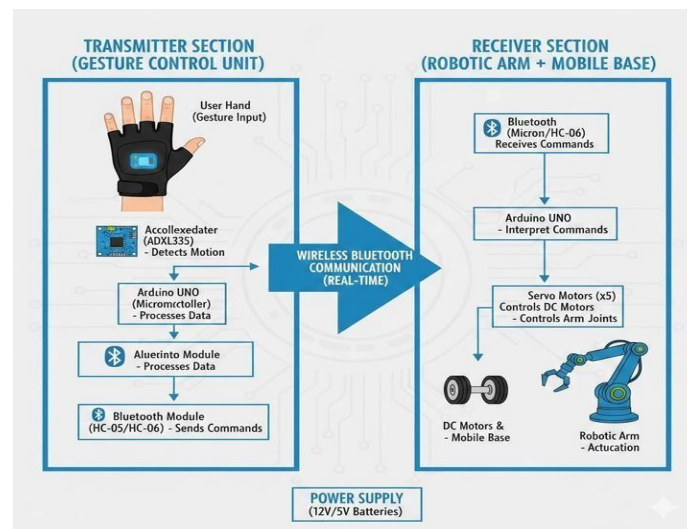


Fig 4.2: Methodology

This methodology shows that a robust and efficiently designed robotic system capable of real-time hand gesture recognition and reliable wireless operation. The integration of accelerometer-based gesture sensing, Arduino-based data processing, Bluetooth communication, servo motor actuation, and DC motor control enables coordinated control of both the robotic arm and the mobile base. This combination forms a complete mechatronic system that supports intuitive human-robot interaction. The systematic design approach, including hardware selection, software development, data processing, threshold logic, safety measures, and step-by-step implementation, contributes to accurate gesture interpretation and smooth robotic motion. Overall, the methodology provides a safe, reliable, and effective solution for gesture-based robotic control with consistent performance and real-time responsiveness. Figure 4.2 shows that the hand gesture-controlled wireless Bluetooth robotic arm with a mobile base. The figure clearly shows the separation between the transmitter section (gesture control unit) and the receiver section (robotic arm with mobile base), connected through real-time Bluetooth communication. In the transmitter section, the user's hand gesture is captured using an accelerometer (ADXL335) mounted on a glove or handheld unit. The accelerometer detects hand

motion and tilt along the X, Y, and Z axes and converts them into analog signals. These signals are processed by an Arduino Uno microcontroller, where gesture data are filtered, mapped, and converted into digital control commands. The processed commands are then transmitted wirelessly using a Bluetooth module (HC-05/HC-06).

Wireless Bluetooth communication provides a real-time link between the transmitter and receiver sections. On the receiver side, the Bluetooth module receives the transmitted commands and forwards them to another Arduino Uno. The Arduino interprets the received commands and controls the actuators accordingly. Servo motors are used to control the robotic arm joints, including base rotation and gripper movement, while DC motors drive the wheels of the mobile base. This allows simultaneous control of robotic arm manipulation and robot navigation. The figure also highlights the power supply arrangement, where appropriate voltage levels (12 V for DC motors and 5 V for Arduino and servo motors) are provided to ensure stable operation. Overall, Fig. 3.5 visually summarizes the complete methodology, showing how hand gestures are sensed, processed, transmitted, and finally converted into coordinated robotic motion, enabling accurate, safe, and real-time gesture-based control[1][2][8][25].

6.3 Hardware Design

The hardware design of the proposed system consists of electronic, electrical, and mechanical subsystems that work together to achieve gesture-based robotic control. Each component is carefully selected to ensure reliable operation, ease of integration, and cost-effectiveness. The Arduino microcontroller used as the main processing unit of the system. It handles sensor input from the accelerometer and generates control signals for servo motors and DC motors. Due to its simplicity, flexibility, and ease of programming, the Arduino provides efficient interfacing with multiple hardware components and supports rapid system development.

An ADXL335 or ADXL345 accelerometer is used to detect hand movements along the X, Y, and Z axes. The sensor produces analog voltage outputs corresponding to the tilt and motion of the hand. It is mounted on a glove or handheld unit worn by the user, allowing natural and intuitive gesture input. Bluetooth modules such as HC-05 or HC-06 are used for wireless communication between the transmitter and receiver sections. These modules operate at a frequency of 2.4 GHz and support UART-based serial communication. With a typical operating range of approximately 10 meters, they enable reliable real-time data transmission between the gesture control unit and the robotic system. Servo motors are used to control the movement of the robotic arm joints, including base rotation, shoulder lifting, elbow bending, wrist movement, and gripper opening and closing. These motors provide high torque and precise angular control, with a typical rotation range from 0° to 180°, enabling accurate positioning and smooth arm motion. DC motors coupled with wheels are used to provide mobility to the robot. These motors are selected for their high speed and high torque characteristics, allowing the robot to move forward, backward, left, and right. The wheel-based mobile platform ensures stable and controlled navigation.

A motor driver such as L298N or L293D is used to control the direction and speed of the DC motors. The motor driver acts as an interface between the Arduino and the motors, supplying sufficient current and protecting the controller from high-power loads. The system is used to powered dual-voltage supply. A 12 V battery is used to drive the DC motors, while a regulated 5 V supply is provided to the Arduino microcontroller and servo motors. This arrangement ensures stable operation of all components. The mechanical structure of the robot includes the chassis, robot arm frame, gears, brackets, and wheels. These components provide mechanical strength, proper alignment of actuators, and support for smooth and stable robotic operation.

6.4 Software Design

The software for the proposed system is developed using the Arduino Integrated Development Environment (IDE). The program is responsible for reading accelerometer values, filtering and mapping sensor data, transmitting and receiving Bluetooth commands, and controlling both servo motors and DC motors. The software plays a critical role in ensuring accurate gesture recognition and smooth robotic motion. The overall code structure with sensor initialization, where the accelerometer and Bluetooth modules are configured for proper operation. The program continuously reads analog values from the accelerometer and maps these values into corresponding digital commands using predefined threshold limits. Based on the processed sensor data, Bluetooth commands are generated and transmitted from the transmitter unit to the receiver unit. On the robot side, the received commands are decoded and

used to control the actuators. The software then drives the servo motors of the robotic arm and the DC motors of the mobile base to perform the desired actions. Several algorithms are implemented in the software to ensure reliable system performance. A calibration algorithm is used to compensate for sensor offset and initial alignment errors. A threshold detection algorithm is applied to convert continuous accelerometer data into discrete motion commands. Motor control algorithms regulate the speed and direction of the DC motors, while servo angle mapping algorithms ensure precise positioning of the robotic arm joints. Command-based wireless communication is used to synchronize the transmitter and receiver units, enabling real-time gesture-based control of the robotic system.

6.5 Communiacion

The communication of the Hand Gesture Controlled Wireless Bluetooth Robotic Arm with Wheels are divided into two section transmitter and receiver that are following:

6.5.1 Transmitter

The transmitter section flowchart describes that the hand gestures converted into wireless control commands. Once the system starts, the accelerometer continuously reads hand movement data along the X, Y, and Z axes. These sensor values represent the tilt and orientation of the user's hand.

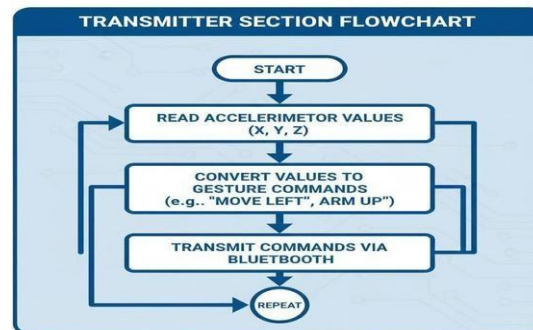


Fig 4.5: Flowchart of the Transmitter Communication

The acquired accelerometer values are then processed and converted into predefined gesture commands based on threshold conditions. For example, specific tilt directions are mapped to commands such as left movement, right movement, arm up, or arm down. After generating the appropriate gesture commands, the transmitter unit sends these commands wirelessly to the receiver unit using a Bluetooth module. This process is executed in a continuous loop, allowing the system to repeatedly read sensor data, generate commands, and transmit them in real time. The repetitive operation ensures continuous gesture tracking and enables smooth, responsive, and uninterrupted control of the robotic arm and mobile base.

6.5.2 Receiver

The receiver section flowchart illustrates the sequence of operations performed by the robotic system after receiving gesture commands from the transmitter unit. The process starts with the initialization of the receiver system. Once the system is active, the Bluetooth module continuously receives command data transmitted from the gesture control unit.

After receiving the Bluetooth commands, the Arduino microcontroller processes the data and identifies whether the command corresponds to robotic arm operation or mobile base movement.

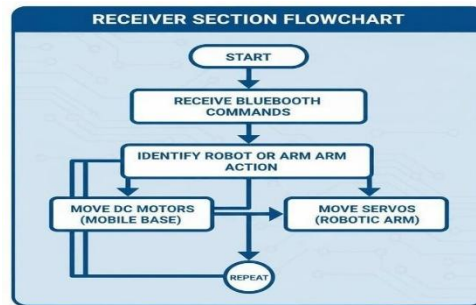


Fig 4.6: Flowchart of the Receiver Communication

Based on this identification, the appropriate control action is selected. If the command is related to robot navigation, the Arduino drives the DC motors of the mobile base through the motor driver to perform movements such as forward, backward, left, or right motion. If the command corresponds to arm control, the Arduino actuates the servo motors to perform operations such as base rotation, arm lifting, wrist movement, or gripper action. The entire process is executed in a continuous loop, allowing the receiver system to repeatedly receive commands, identify actions, and control the motors in real time. This repetitive operation ensures smooth, responsive, and uninterrupted gesture-based control of both the robotic arm and the mobile base.

6.6 Threshold logic Control

Accelerometer data obtained from hand gestures is normally noisy and not always linear due to hand vibrations, sensor sensitivity, and environmental disturbances. To stabilize system performance, data processing techniques such as noise filtering, data smoothing, and threshold-based decision logic are applied before command generation. Initially, the Arduino reads the analog acceleration values along the X, Y, and Z axes from the accelerometer. Noise filtering and smoothing techniques are used to reduce fluctuations and improve the reliability of the sensed data. After

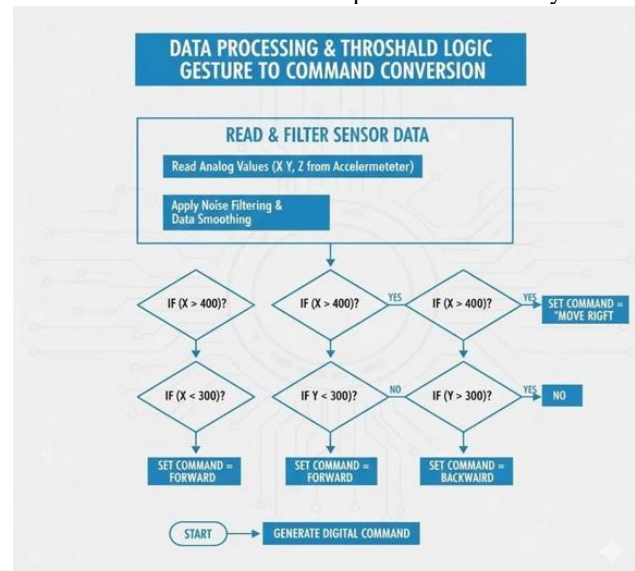


Fig 4.6: Data processing & Threshold Logic Gesture to Command Conversation

preprocessing, threshold detection logic is applied to convert continuous analog values into discrete digital commands. Specific threshold values are defined for each axis to determine the direction of motion. For the X-axis, when the accelerometer value exceeds 400, a right movement command is generated, while values below 300 correspond to left

movement. Similarly, for the Y-axis, values greater than 400 result in a forward movement command, whereas values less than 300 generate a backward movement command. These threshold limits ensure clear separation between different gesture commands. Based on these predefined conditions, the Arduino generates the corresponding digital control command and transmits it to the receiver unit. This threshold-based gesture-to-command conversion minimizes false triggering caused by minor sensor variations and ensures smooth, accurate, and responsive robotic motion.

7 Result

The results of the hand gesture controlled wireless Bluetooth robotic arm with a mobile wheeled platform is provide the better gesture recognition accuracy, system response time, reliable wireless communication with accurate robotic arm movement and its also demonstrate that the system operates efficiently and successfully meets the defined design objectives, validating its suitability for real-time gesture-based robotic control applications. All hardware components of the proposed system were individually tested prior to full integration to ensure functionality and reliable performance. Flex sensors showed a 90–93% accuracy in finger position detection with stable voltage output. The accelerometer detected hand motion effectively, with a response time of 20–30 ms, making it suitable for gesture-controlled applications. Bluetooth modules successfully paired within 1–2 seconds, maintaining a wireless range of 8–10 meters, with no packet loss and low latency below 50 ms. Servo motors performed accurately with a positioning precision of ± 3 degrees and a lifting capacity of 100–150 grams. The robot's DC motor-driven base exhibited reliable motion control at speeds of 0.3–0.6 m/s, while motor driver modules handled loads efficiently without overheating.

Software testing of a gesture recognition algorithm revealed high accuracy (92-96%) and reliability in real-time performance. The system demonstrated precise mapping of glove-mounted sensors to robotic arm movements, with a 96% success rate in gesture execution. Combined system response time ranged from 80-120 ms, compatible with small-scale robotic applications requiring immediate control. Testing encompassed object manipulation, mobile navigation, and multitasking capability. The robotic arm efficiently handled lightweight objects and displayed stable operation, even over 10-15 minutes of continuous use. Wireless communication ranged 8-10 meters, maintaining reliable data transmission. Overall, the system showed low error rates (under 5%) and effective integration of components.

References

- [1] S. Kumar, P. Verma, and A. Singh, "Advances in Robotic Systems and Wireless Automation," *International Journal of Robotics Research*, vol. 40, no. 3, pp. 245–259, 2022.
- [2] M. Rahman and J. Kim, "Gesture-Based Control Systems for Robotics: A Review," *IEEE Access*, vol. 9, pp. 122345–122362, 2021.
- [3] N. Gupta, R. Sharma, and T. Goyal, "Design and Implementation of a Hand Gesture Controlled Robotic Arm," *Procedia Computer Science*, vol. 192, pp. 1122–1130, 2021.
- [4] B. Chen and Y. Zhao, "Wireless Communication Protocols for Robotics: Comparative Study of Bluetooth, Zigbee, and Wi-Fi," *Robotics and Autonomous Systems*, vol. 128, pp. 103509, 2020.
- [5] A. Kumar and B. Sharma, "Wireless Control of a Robotic Arm Using Bluetooth and MEMS Sensors," *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, vol. 8, no. 2, pp. 33–39, 2020.
- [6] H. Zhang, L. Wang, and X. Li, "Robotic Applications in Industrial Automation: A Comprehensive Survey," *Automation Science and Engineering Journal*, vol. 17, no. 1, pp. 80–97, 2020.
- [7] F. Zadeh and M. Hossain, "Human–Machine Interaction through Wearable Sensors: A Review," *Sensors and Actuators A: Physical*, vol. 305, pp. 111918, 2020.
- [8] R. Dutta and P. Mitra, "Assistive Robotics for Physically Challenged Using Hand Gestures," *IEEE Transactions on Human-Machine Systems*, vol. 50, no. 4, pp. 289–298, 2021.
- [9] R. Bharadwaj, S. Gawai, and V. Gulhane, "Hand Gesture Control Robo Car using Machine Learning," *IEEE Conference on Electronics, AI and Robotics*, 2025.
- [10] Y. Zhang and Y. Liu, "Design of Automatic Control Manipulator," *Proceedings of the 4th International Symposium on Robotics Engineering*, IEEE, 2025.
- [11] A. Jain, R. S. Tomar, and P. Sharma, "IoT and AI Integration in Smart Robotics," *Journal of Intelligent and Fuzzy Systems*, vol. 41, no. 6, pp. 7503–7514, 2021.
- [12] K. Karthikeyan and M. Kannan, "Machine Learning-Based Gesture Recognition for Robotic Arm Control," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 12, no. 5, pp. 589–595, 2021.

- [13] P. Roy and M. Chatterjee, "Real-Time Gesture Controlled Robotic Arm Using MEMS and Arduino," *Procedia Technology*, vol. 26, pp. 1325–1333, 2020.
- [14] V. Jaiswal and A. Kulkarni, "Optimized Gesture Recognition System Using Accelerometer and Kalman Filter," *International Journal of Engineering Science and Computing*, vol. 10, no. 8, pp. 27632–27638, 2020.
- [15] D. Patel and K. Mehta, "Wireless Multi-Axis Gesture Controlled Robot Using Bluetooth," *International Journal of Engineering and Technology Innovation*, vol. 11, no. 3, pp. 129–139, 2021.
- [16] P. Dey, S. Das, and B. Ghosh, "Accelerometer-Based Gesture Controlled Robotic Arm," *International Journal of Computer Applications*, vol. 178, no. 4, pp. 12–19, 2021.
- [17] L. Singh and J. George, "Implementation of HC-05 Bluetooth Based Robotic Arm," *International Journal of Emerging Technology and Advanced Engineering*, vol. 11, no. 2, pp. 87–93, 2021.
- [18] A. Sharma and M. Raj, "Low-Cost Wireless Control Mechanism for Robots Using Arduino and Bluetooth," *International Research Journal of Engineering and Technology (IRJET)*, vol. 8, no. 9, pp. 1905–1912, 2021.
- [19] S. Patel, T. Khatri, and M. Joshi, "Bluetooth-Based Wireless Control of Mobile Robots," *International Journal of Science and Research (IJSR)*, vol. 10, no. 2, pp. 52–60, 2021.
- [20] J. Lin, T. Kim, and C. Park, "IoT-Based Remote Control of Gesture Robots Using AI Edge Processing," *IEEE Internet of Things Journal*, vol. 8, no. 12, pp. 9854–9864, 2021.
- [21] L. He and F. Tan, "Cloud Robotics: Integration of IoT and Gesture Control," *Journal of Ambient Intelligence and Humanized Computing*, vol. 13, pp. 10921–10935, 2022.
- [22] H. Zhang, L. Wang, and X. Li, "Industrial Robotic Automation Systems: A Review," *Automation Science and Engineering Journal*, vol. 17, no. 1, pp. 80–97, 2020.
- [23] T. Kato and M. Sakamoto, "Medical Robotics with Gesture Interfaces for Rehabilitation," *Biomedical Engineering Letters*, vol. 11, no. 3, pp. 337–349, 2021.
- [24] S. Shukla, D. Patel, and K. Mehta, "Gesture Controlled Robots for Search and Rescue Operations," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 10, no. 7, pp. 11–18, 2021.
- [25] A. Bhattacharya and N. Ghosh, "Educational Robotics Using Arduino and Wireless Control," *International Journal of Research in Engineering and Technology*, vol. 9, no. 3, pp. 445–452, 2020.
- [26] M. Alvi, K. Raza, and P. Tiwari, "AI and IoT-Enabled Gesture Recognition for Robotic Arm Control," *IEEE Internet Computing*, vol. 25, no. 5, pp. 68–77, 2021.
- [27] A. Ortega and D. Silva, "Machine Learning Integration in Gesture-Controlled Robotic Manipulation," *IEEE Transactions on Cybernetics*, vol. 54, no. 6, pp. 5271–5282, 2024.
- [28] F. Hassan, R. Zafar, and A. Chaudhry, "Bluetooth 5.3 Enabled Multi-Robot Coordination for Industrial Automation," *IEEE Sensors Journal*, vol. 24, no. 2, pp. 1934–1945, 2024.
- [29] Y. Wang, C. Xu, and L. Zhang, "IoT-Driven Mobile Robotics: Future Prospects and Challenges," *IEEE Access*, vol. 12, pp. 78321–78340, 2024.
- [30] L. Li and C. Chen, "Smart Servo Feedback Systems for Adaptive Manipulation in Robotics," *Mechatronics*, vol. 82, pp. 102678, 2023.
- [31] Z. Zhenyu, L. Wang, and Y. Chen, "Gesture-controlled wheelchair using a three-axis accelerometer," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 18, no. 3, pp. 317–324, 2010.
- [32] J. Liu, H. Sun, and Q. Wang, "Accelerometer-based wrist motion control for robotic arm manipulation," *International Journal of Advanced Robotic Systems*, vol. 9, no. 4, pp. 1–10, 2012.
- [33] H. Kim and J. Park, "Hand-motion based industrial robotic arm control using accelerometer and gyroscope sensors," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 10, pp. 6369–6377, 2015.
- [34] R. Gupta and A. Sharma, "Smartphone controlled robot car using Bluetooth technology," *International Journal of Engineering Research and Technology (IJERT)*, vol. 5, no. 4, pp. 245–249, 2016.
- [35] M. Faisal, A. Khan, and S. Ahmed, "Bluetooth-based wireless control of robotic arms for hazardous environment applications," *International Journal of Advanced Robotics and Automation*, vol. 3, no. 2, pp. 1–7, 2018.
- [36] K. Singh and P. Verma, "Design and development of a 4-DOF robotic arm using servo motors," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 6, no. 5, pp. 3641–3647, 2017.
- [37] J. Park, S. Lee, and H. Kim, "PID-based dynamic control of servo motor driven robotic arms for medical applications," *IEEE Transactions on Industrial Electronics*, vol. 61, no. 8, pp. 4168–4177, 2014.
- [38] A. A. Shukla, R. Verma, and S. Jain, "Design and implementation of a DC motor driven mobile robot using L298N motor driver," *International Journal of Engineering Research and Technology (IJERT)*, vol. 8, no. 6, pp. 512–516, 2019.
- [39] A. Kumar, S. Patel, and R. Meena, "Multi-purpose mobile robot using DC motors with obstacle detection," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 9, no. 4, pp. 2271–2278, 2020.
- [40] S. Rathod and M. Patel, "Design of a gesture-controlled pick-and-place robotic system," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 7, no. 4, pp. 1962–1968, 2018.
- [41] K. Harish and M. Reddy, "Hand gesture controlled mobile robotic vehicle," *International Journal of Engineering Research and Technology (IJERT)*, vol. 9, no. 3, pp. 101–105, 2020.