



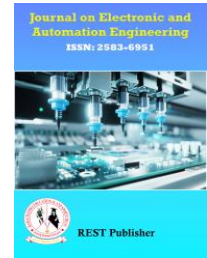
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## Gesture Driven Robotic Control using MEMS Technology

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**Abstract:** A MEMS-based gesture-controlled robot is a type of robot that can be controlled by our hand gestures rather than plain old switches or keypads. In the future, there is a possibility of creating robots that can interact with humans in a natural way. Therefore, our target interest lies in gesture interfaces based on hand movements. An innovative formula for gesture recognition has been developed to identify unique action signs made through hand movements. A MEMS sensor was used to implement this, and an ultrasonic sensor for the robustness was used. A program has been written and implemented using a microcontroller system to meet our requirement. When the results of the experiment are observed, it proves that our gesture formula is very efficient, and it enhances the natural way of intelligence and is even integrated into a simple hardware circuit.

**Keywords:** Gesture Recognition, MEMS Sensor, Raspberry Pi Pico, Human-Machine Interaction, Robotic Control.

### 1. INTRODUCTION

Technological advancements have significantly enhanced the quality of life by automating complex tasks and simplifying routine operations. One such advancement is gesture recognition, a field that has garnered considerable attention within domains such as image processing and human-computer interaction. As our reliance on human-machine interfaces continues to grow, the development of more intuitive user interface technologies becomes increasingly essential. Gestures, being natural and expressive forms of communication, offer a seamless and user-friendly method for humans to interact with computers and machines, thereby improving the efficiency and ease of such interactions.

In the ever-advancing domain of robotics, creating intuitive and human-friendly interaction methods has become a top priority. This has led to the rise of gesture-controlled systems, which utilize Micro-Electro-Mechanical Systems (MEMS) to detect and interpret human motion. MEMS devices, such as accelerometers and gyroscopes, are especially well-suited for this purpose due to their compact design, low power requirements, and high responsiveness. Their ability to detect fine, precise movements makes them ideal for wearable technologies, where capturing human gestures accurately is critical.

Building upon this concept, we have developed an innovative smart diving glove capable of recognizing static hand signals commonly used in underwater communication. By incorporating MEMS-based sensors, this glove can accurately detect and interpret hand gestures. Beyond diving, this type of gesture control system holds great potential in educational settings. For example, students can manipulate learning tools like educational robots or virtual simulations using simple hand gestures. This approach not only makes learning more interactive and immersive but also extends the benefits to remote education. Learners can engage with virtual experiments and laboratory simulations from their own homes, thereby expanding access to hands-on educational experiences regardless of location.

The integration of MEMS technology into gesture-based robotic control systems is a significant step forward in the field of human-robot interaction. By providing a more natural, intuitive, and efficient interface, this technology has the potential to revolutionize a variety of industries and applications. As research and development continues to advance, we can expect to see even more innovative and impactful applications of MEMS-based gesture control in

the future. Continued exploration of this technology will undoubtedly lead to smarter, more responsive, and user-friendly devices that will improve our daily lives.

## 2. LITERATURE SURVEY

In a 2023 study titled “MEMS-Based Gesture Controlled Robot,” Rohitha et al. describe the design and implementation of a robot that responds to hand gestures using MEMS-based sensors. The system uses accelerometers and gyroscopes to detect motion, which are then converted into robot actions by a microcontroller. Communication between the controller and the robot is facilitated by a ZigBee transmitter, which allows commands to be sent wirelessly and interpreted in real time. This method provides an intuitive way to control robotic systems, especially useful in hazardous environments and industrial automation where direct human involvement would be dangerous.

In a more recent work, Kiran D. (2024) presents “Design and Development of a Gesture Controlled Robotic Arm,” which focuses on creating a robotic arm that is fully controlled through hand gestures. The system includes flex sensors, servo motors, and an Arduino Nano microcontroller that interprets specific gestures and moves the robotic arm accordingly. This wireless system ensures responsive and precise movement, which proves beneficial for applications in healthcare, safety, and factory automation. The study underscores the important role of real-time communication in achieving seamless human-machine interaction.

Another notable contribution comes from Abhinaya C. (2023), who is researching on the topic of “Gesture-based motor control using MEMS accelerometer.” The model developed in this study features a three-axis accelerometer and embedded software to process gesture data and generate appropriate motor responses. The proposed gesture-controlled interface shows promise for controlling robotic systems in fields such as construction, medical procedures, and hazardous material handling, where precise and contactless control is essential.

Additionally, a comprehensive review in the International Journal of Research and Analysis Technology (IJRAT) discusses various implementations of gesture-controlled robots using MEMS accelerometers. The review highlights the advantages of MEMS technology in human-machine interaction, emphasizing their small size, low power consumption, and high sensitivity. This review addresses the inherent challenges of gesture recognition – signal noise and gesture ambiguity – and explores strategies to improve the accuracy and reliability of these systems.

“Efficient and Feasible Gesture Controlled Robotic Arm” A study published in the International Journal of Research and Management of Emerging Technologies (IRJMETS) reviews different techniques for controlling robotic arms using manual gestures. The paper highlights the efficiency

## 3. BLOCK DIAGRAM

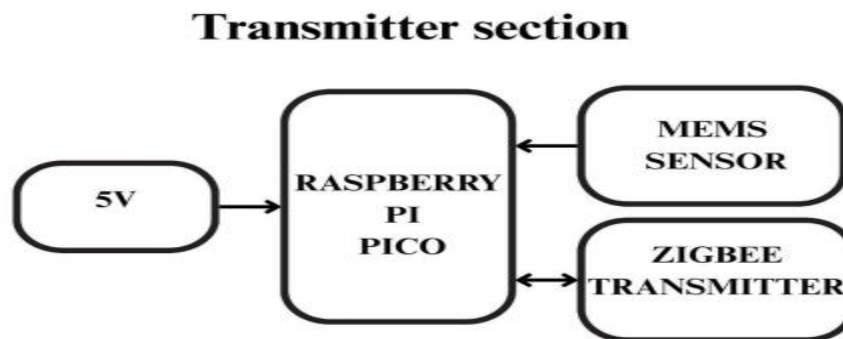


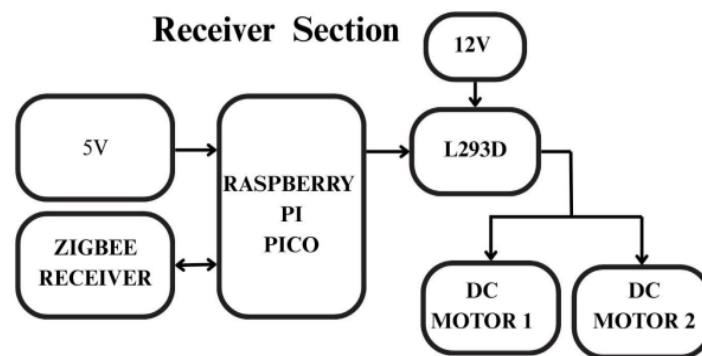
FIGURE 1. Block Diagram of Transmitter

The block diagram illustrates the transmitter section of a wireless sensor system that utilizes a Raspberry Pi Pico microcontroller for data acquisition and communication. At the core of the system is the Raspberry Pi Pico, which acts as the central processing unit, coordinating the operation of the connected components. The Pico is powered by a 5V power supply, ensuring that the microcontroller and its peripherals receive the necessary voltage to operate effectively. Connected to the Raspberry Pi Pico are two critical components: a MEMS sensor and a Zigbee transmitter.

The MEMS (MicroElectro-Mechanical Systems) sensor is responsible for detecting physical changes, such as The system begins by detecting motion or acceleration using a MEMS (Micro-Electro-Mechanical Systems) sensor, which converts physical movement into corresponding electrical signals. These signals, primarily containing acceleration data, are then read and processed by the Raspberry Pi Pico, a compact microcontroller at the heart of the setup. Acting as the central control unit, the Raspberry Pi Pico manages data acquisition and ensures communication between connected components. It is powered by a 5V supply, providing sufficient voltage for stable operation.

Once the motion data is processed by the Raspberry Pi Pico, it is forwarded to a Zigbee transmitter. Zigbee is a widely used wireless communication protocol designed for short-range, low-power data transmission. In this context, the Zigbee module wirelessly sends the sensor data to a receiver located in another part of the system, enabling real-time communication without the need for physical wiring.

This transmitter section is engineered to collect dynamic motion or acceleration data, process it locally via the microcontroller, and wirelessly transmit it using Zigbee technology. Such a configuration is especially suitable for applications that require gesture-based control, remote monitoring, or any system that depends on real-time transmission of movement data. The block diagram associated with this setup clearly illustrates how each component—from the MEMS sensor to the Zigbee transmitter—is integrated with the Raspberry Pi Pico to deliver a robust and efficient wireless sensing solution.



**FIGURE 2.** Block Diagram of Receiver

The receiver section of this wireless control system is designed to drive two DC motors using data transmitted from a remote source. At the center of this configuration is the Raspberry Pi Pico, which serves as the main processing unit. Powered by a 5V supply, the Pico receives data wirelessly through a Zigbee receiver module, which communicates with the corresponding transmitter from the sender side. The transmitted data—typically representing motion or gesture instructions collected from a MEMS sensor—is interpreted by the Raspberry Pi Pico to generate appropriate motor control commands.

To drive the motors, the Raspberry Pi Pico sends control signals to an L293D motor driver IC, which is independently powered by a 12V supply. The L293D is a dual H-bridge driver capable of operating two DC motors simultaneously. It acts as an interface between the low-power logic of the Pico and the higher power requirements of the motors. The L293D outputs are connected directly to Motor 1 and Motor 2, allowing the Raspberry Pi Pico to control their direction and speed based on the incoming Zigbee data.

This configuration is particularly suited for robotic systems, such as wireless robot cars or gesture-controlled robots, where remote, real-time control of motion is essential. In summary, the block diagram illustrates how Zigbee-based wireless communication, combined with the processing capabilities of the Raspberry Pi Pico and the motor-driving functionality of the L293D, enables precise and efficient control of robotic motion using gesture or movement inputs.

## 4. FLOWCHART

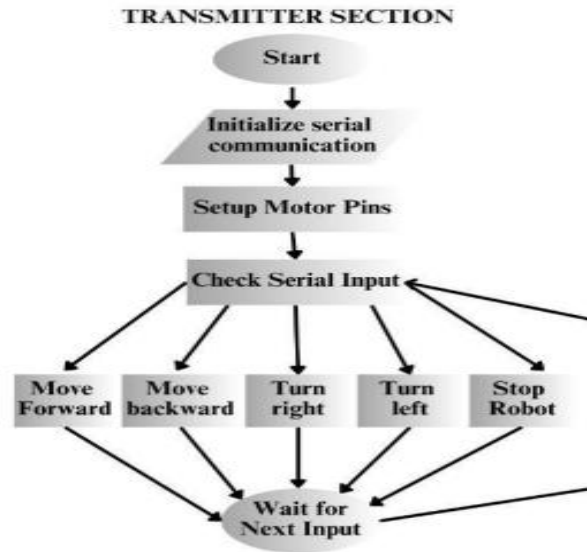


FIGURE 3. Flowchart of Transmitter

The flowchart provided outlines the Transmitter Section of a robot control system, detailing the sequence of operations for managing robotic movements via serial communication. The process begins with a Start node, initiating the system. The first operation is to Initialize Serial Communication, which sets up the communication link between the transmitter (likely a microcontroller) and the receiver (the robot). Following this, the system proceeds to Setup Motor Pins, which configures the microcontroller's pins to control the motor driver, enabling physical movement of the robot. Once the hardware is initialized, the system continuously Checks Serial Input for any incoming commands. Depending on the input received, the system directs the robot to perform one of several actions: Move Forward, Move Backward, Turn Right, Turn Left, or Stop Robot. Each of these actions is linked back to a common step — Wait for Next Input — signifying that after executing a command, the system loops back to listen for the next instruction. This cyclical structure ensures that the robot responds in real time to a continuous stream of commands, maintaining dynamic control over its behavior through the transmitter interface. The process begins with system initialization, where the microcontroller starts by setting up serial communication. This step is essential as it establishes the connection for transmitting commands, typically using wireless modules like Zigbee or Bluetooth. Following this, the system configures the motor control pins, assigning specific GPIO pins to manage the direction and movement of the robot via a motor driver such as the L293D. Once the setup is complete, the system enters a loop where it constantly checks for incoming serial data. Based on the input received—whether it's a command to move forward, backward, turn left, turn right, or stop—the corresponding motor actions are triggered. Each movement command is executed by manipulating the motor driver pins to control the direction and speed of the motors. After executing a command, the system loops back to await the next input, ensuring continuous, real-time control of the robot. This structured approach provides a responsive and efficient way to manage robotic motion from a remote transmitter, enabling precise navigation and user interaction.

## 5. HARDWARE COMPONENTS

### ADXL Sensor (Mems)

MEMS (Micro-Electro-Mechanical System) sensors convert a physical or environmental stimulus into an electrical signal, which can then be measured or analyzed. This is achieved through the usage of tiny mechanical structures and electrical circuits integrated onto a single chip. The smaller size of MEMS devices makes them highly reliable and functional among the operations of sensors, processing units, and actuators. This technology is begin used to create tiny sensors and actuators that can detect and respond to gestures.

### ADXL345 Sensor:

Passive sensors are used to detect the linear and rotational motion of an object. There are two types of passive sensors - accelerometers that detect linear acceleration and gyroscopes that detect rotational motion. Accelerometers and gyros are widely used in many applications, including aerospace, military, automotive, mobile phones, and consumer electronics. For example, in mobile phones, gyroscope and accelerometer sensors are used for screen rotation, gaming, virtual reality, and augmented reality applications. In automobiles, accelerometers and gyroscopes are used to detect vehicle rollover, airbag deployment control, ABS, active suspension, traction control, and seat belt control. Many military applications, such as smart munitions, flight control, etc., also use these sensors. In aerospace applications, these sensors are used to measure microgravity and monitor the movement and rotation of equipment/devices. The ADXL345 is a compact 3-axis accelerometer with a dynamic range of +/-16g, 13-bit resolution, 3200Hz maximum bandwidth, and a maximum data rate of 3200 times per second. It is a digital accelerometer sensor and outputs digital values of acceleration in three axes. The sensor outputs data formatted as 16-bit two's complement, which is accessible via SPI or I2C interfaces. This sensor is very low power and consumes only 23 uA in measurement mode and 0.1 uA in standby mode. The ADXL345 is a compact, high-performance accelerometer that offers user-configurable resolution and selectable measurement ranges, which can be adjusted via serial communication commands. One of its key features is its support for versatile interrupt functionality, allowing users to assign different sensing events to either of its two dedicated interrupt pins. Built-in detection capabilities include free-fall detection and tap recognition, making the sensor suitable for a wide range of interactive and safety-related applications. Additionally, the ADXL345 is capable of identifying motion and inactivity by comparing real-time acceleration values against predefined threshold limits set by the user. It can accurately measure both static acceleration—such as gravitational force—and dynamic acceleration, which occurs due to movement or sudden impact. Physically, the sensor is housed in a 14-lead LGA package with dimensions of just 3mm x 5mm x 1mm, making it ideal for space-constrained applications. Thanks to its small size and versatile features, the ADXL345 is widely used in portable and embedded systems, including smartphones, handheld gaming devices, navigation tools, pointing devices, and hard drive protection systems. It is also employed in medical equipment and industrial monitoring systems, where precise motion detection is essential.

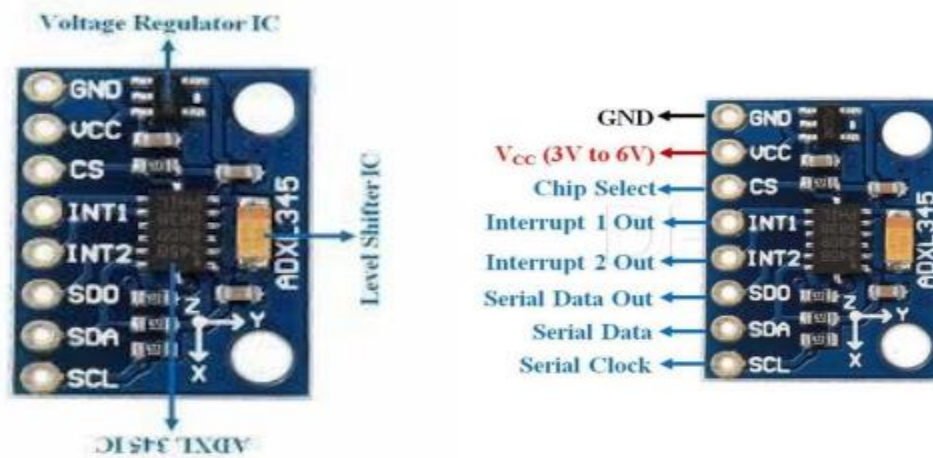


FIGURE 4. Internal architecture of ADXL sensor

The sensor may be available as a module where all or few pins may be available for interfacing with a circuit. In the sensor module shown below, only pins necessary for interfacing with a circuit (I2C, SPI, Interrupts, and power supply) are available for use. Other pins are hard-wired on the module like with pull-up resistors for I2C lines. It can be noted that axes of acceleration are indicated on the module. Otherwise, the axes of accelerations can be found with respect to the top view of the sensor, as shown below:

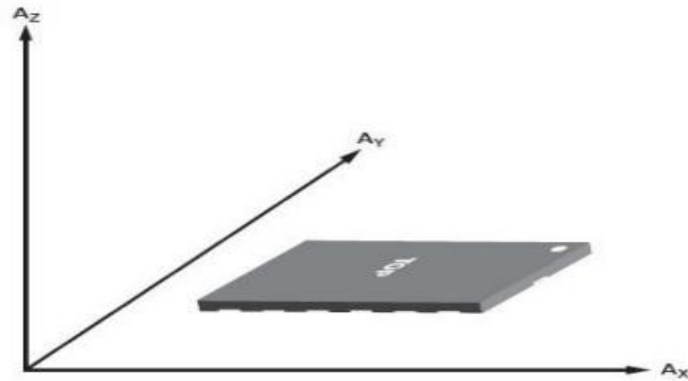


FIGURE 5. Example of ADXL345 accelerometer sensor axis.

The ADXL345 accelerometer is capable of sensing both static acceleration—such as the force of gravity—and dynamic acceleration resulting from motion, vibration, or shock. The sensor responds to changes in orientation and movement, making it suitable for applications such as tilt detection, free-fall sensing, and motion tracking. The device produces output based on its alignment with the gravitational field, providing valuable data that can be interpreted in real time.

### Working Principle of the ADXL345

The ADXL345 is a three-axis MEMS accelerometer, meaning it can detect acceleration along the X, Y, and Z axes. Internally, the sensor is built using polysilicon micromachining technology, forming a structure suspended above a polysilicon wafer. It functions as a capacitive accelerometer, where a central proof mass is suspended by polysilicon springs. When acceleration occurs along any axis, this proof mass shifts, altering the distance between itself and fixed electrodes. These changes unbalance the differential capacitors, which in turn generate a voltage signal proportional to the applied acceleration. A phase-sensitive demodulation technique is used to accurately determine the direction and magnitude of the acceleration force.

### Communication and Interfacing

The ADXL345 can be easily interfaced with microcontrollers or embedded systems through digital communication protocols, including I2C, 3-wire SPI, or 4-wire SPI. These interfaces allow a controller to read from or write to the sensor's internal registers, enabling real-time interaction and data acquisition.

### Usage of the ADXL345 Module

The ADXL345 module typically comes with eight pins, simplifying integration with a microcontroller. For a basic setup with an Arduino, the VCC and GND pins of the module should be connected to the corresponding 5V and ground pins of the Arduino board. The SCL (clock) and SDA (data) lines are then connected to the Arduino's I2C pins. The core sensing mechanism of the module is based on capacitance variation between fixed and moving plates. When acceleration is applied to any axis, the relative positions of these plates shift, leading to a change in capacitance. This variation is converted into an output signal that reflects the intensity and direction of the acceleration.

## 6. RESULT

MEMS based Gesture Controlled Robot is a kind of robot that can be by our hand gestures rather than an ordinary old switches or keypad. In Future there is a chance of making robots that can interact with humans in a natural manner. Hence our target interest is with hand motion-based gesture interfaces. An innovative Formula for gesture recognition is developed for identifying the distinct action signs made through hand movement. Upon noticing the results of experimentation proves that our gesture is very competent and it's also enhanced the natural way of intelligence and also assembled in a simple hardware circuit.

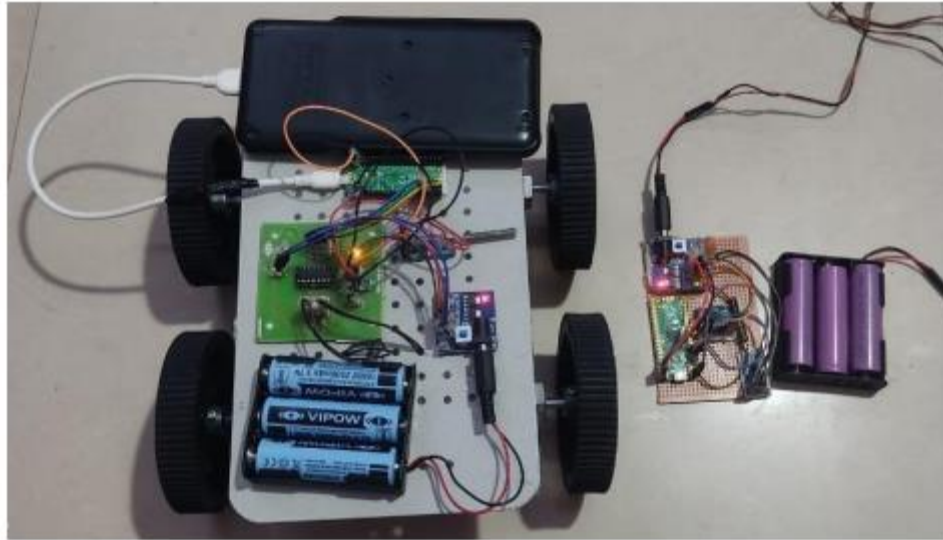


FIGURE 6. Prototype

The main advantages of using MEMS in gesture control include their small size, low cost, and high precision. However, challenges such as signal processing complexity and the need for robust algorithms to accurately interpret gestures must be addressed to advance this technology further. Overall, the combination of MEMS technology and gesture recognition represents a significant step towards more responsive and user-friendly robotic systems, paving the way for innovative applications and enhanced human-robot interaction.

## 7. ADVANTAGES AND APPLICATIONS

### Advantages

One of the primary benefits of gesture-controlled robotic systems is their ability to provide contactless operation, allowing users to control machines remotely without any physical interaction—an especially valuable feature for maintaining hygiene and safety. The use of natural hand movements makes these systems intuitive and user-friendly, removing the need for complicated control interfaces. Equipped with MEMS sensors, the system offers high precision and real-time responsiveness, ensuring accurate motion detection with minimal delay.

Another major advantage is the portability and energy efficiency of MEMS-based devices. Their compact size and low power consumption make them ideal for wearable and mobile applications. The system is also highly versatile, capable of being integrated into a wide range of robotic platforms used in different environments and industries. With the inclusion of wireless communication protocols like ZigBee, users can operate robots from a distance, enabling flexible and remote control.

Additionally, the system is scalable, meaning it can be expanded to manage multiple robots or functions through different gesture sets. This adds flexibility for more complex applications. By enabling remote operation, the system significantly enhances safety, particularly in hazardous environments where human presence poses a risk. From a cost perspective, the use of affordable components such as MEMS sensors and Raspberry Pi Pico microcontrollers makes the solution highly cost-effective. Finally, the system offers a high degree of customizability, allowing developers to program gesture commands and adjust sensitivity thresholds according to specific tasks or user preferences.

### Applications

Gesture-controlled robotic systems have a wide range of practical applications across various industries. In the field of industrial automation, these systems allow for the remote operation of robots in hazardous or inaccessible environments, such as chemical plants, high-temperature areas, or confined spaces, thereby minimizing human exposure to danger. In medical and rehabilitation settings, gesture-based control can assist individuals with limited mobility by enabling them to operate robotic limbs or assistive technologies using simple hand movements.

In the defense and surveillance sectors, these systems offer a silent and contactless way to control robots or drones, allowing for discreet monitoring and operations in combat zones without putting personnel at risk. Similarly, during search and rescue missions, gesture-controlled robots can navigate disaster-stricken areas, including collapsed structures or toxic environments, where sending in human rescuers would be too dangerous.

The technology also proves valuable in-home automation and assistive technology, offering gesture-based control for smart devices, particularly benefiting the elderly and individuals with disabilities. In construction and heavy machinery operations, remote control of equipment through gestures enhances safety by reducing the need for workers to be present in dangerous zones.

Space exploration is another domain where this technology shines, as it enables astronauts to remotely operate robotic arms or vehicles where direct human control is impractical or impossible. In agriculture, robotic systems controlled via hand gestures can be used for precision tasks such as crop spraying or automated harvesting, improving efficiency and reducing labor demands.

Overall, the combination of wireless communication (like ZigBee), scalability, and safety-focused design makes these systems suitable for a broad array of environments and tasks. The ability to expand gesture sets for controlling multiple robots or devices and the enhanced safety provided by remote, contactless operation underline the system's versatility and practical value across domains.

## 8. CONCLUSION AND FUTURE SCOPE

The proposed system introduces an intuitive method for controlling robots using hand gestures, greatly enhancing the interaction between humans and machines. By leveraging MEMS (Micro-Electro-Mechanical Systems) sensors, such as accelerometers, the system is capable of accurately capturing real-time hand motion. This data is processed using the Raspberry Pi Pico, a compact and cost-efficient microcontroller ideal for embedded applications. The design offers a clear advantage over conventional control methods by reducing physical strain and improving accessibility, especially for users with mobility limitations.

The system's modular design also supports expansion through wireless communication modules, enabling remote control functionality. Its adaptability makes it suitable for various fields, including surveillance, industrial automation, and assistive robotics. In summary, gesture-controlled robotic systems using MEMS technology represent a promising direction in human-robot interaction. These systems effectively translate physical gestures into robotic actions, thanks to the high sensitivity, precision, and affordability of MEMS sensors.

However, to fully realize their potential, challenges such as complex signal interpretation, gesture variability, and the requirement for robust processing algorithms must be addressed. Advancing this technology further will involve improvements in sensor integration, computational efficiency, and interface design.

### Future Enhancements

**Gesture Recognition with Machine Learning:** Future iterations of this system can benefit from integrating lightweight machine learning models, such as Tiny ML, to enhance gesture classification accuracy. These models can improve the adaptability of the system while minimizing false detections, resulting in a smoother and more responsive user experience. **Wireless Communication Integration:** The addition of ZigBee, Bluetooth, or Wi-Fi modules will enable real-time remote control, opening the door for multi-device coordination and greater user mobility. **Advanced Sensor Fusion:** By combining data from multiple MEMS sensors—such as accelerometers, gyroscopes, and magnetometers—using sensor fusion techniques, the system can detect more complex and multidimensional gestures, thereby increasing recognition accuracy and robustness. **Multimodal Interaction (Voice + Gesture):** Incorporating voice recognition alongside gesture-based input can lead to the creation of multimodal control interfaces, offering users more intuitive and flexible ways to interact with robotic systems. **Assistive Technology Applications:** The system holds great potential for assistive use cases, such as controlling wheelchairs, robotic prosthetics, or home automation devices. This can greatly improve the independence and quality of life for individuals with physical impairments. **Miniaturization and Wearability:** Future designs could embed the entire control system into compact wearable devices, such as smart gloves or wristbands, making the technology portable, ergonomic, and user-friendly. **Cloud Connectivity and Analytics:** Integration with IoT platforms would allow gesture data to be stored, analyzed, and monitored in the cloud. This can enable features such as usage analytics, real-time diagnostics, and AI model refinement. **Industrial and Defense Use**

Cases: In sectors such as manufacturing and defense, gesture-controlled systems can enable safe and efficient control of robots or machinery in hazardous or high-risk environments, reducing the need for direct human involvement.

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