DEVELOPMENT OF ZIGBEE BASED TELE OPERATED MULTIPURPOSE ROBOTIC ARM WITH HAND GESTURE RECOGNITION

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ABSTRACT

The integration of technologies like Electronics and Mechanical has emerged a new branch which is most famously called Mechatronics. Robotics is a part of Mechatronics. Robotics refers to duplication of human actions by machines. Robotics is a very vast field that has helped us make some wonderful machines that assist us in our daily lives. Typical industrial robots usually perform tasks that are difficult, dangerous and too complex. They lift heavy weights, and a lot of manual work such as welding can be done using robots. They can perform the same course of action in lesser time with more accuracy. Many people have used various technologies to build such kind of robotic arm with wired or wireless communication methodologies. This proposed robotic arm is focused on developing a system that works wirelessly to recognize and control the robotic arm by using various methodologies such as hand gesture recognition technology, Zigbee wireless communication technology, MEMS-3 axis accelerometers, flex sensors etc. The combination of such latest technologies in a single platform has posed real challenge to design and develop. Hence, this work is
undertaken to design and develop Zigbee based tele-operated multipurpose robotic arm with gesture recognition. Though the working of a robotic arm is very simplified, the implementation of this arm requires a good knowledge of Engineering Mechanics, Arduino platform, High end Atmega328 AVR RISC microcontroller, Electromechanical Devices mainly sensors, Mechanical Robotic Arm setup, Rover assembly and Embedded Systems as well.

**Key words:** Atmega328 AVR RISC microcontroller, Arduino Duemilanove Platform, Flex sensor (hand gesture sensor), Zigbee, MEMS-accelerometer, Rover assembly.


1. **INTRODUCTION**

When humans started wishing to become God, they made robots in order to compete with God. When we try to design robot as an alternative for a human being, we have to visualize the brain of a human with software and also simulate the organs of humans with mechanical equipment’s.

Robotics is a current emerging technology in the field of science. Nowadays, robots are increasingly being integrated into working tasks to replace humans especially to perform the repetitive task. In general, robotics can be divided into two areas, industrial and service robotics these robots are currently used in many fields of applications including office, military tasks, hospital operations, dangerous environment and agriculture. Besides, it might be difficult or dangerous for humans to do some specific tasks like picking up explosive chemicals, defusing bombs or in worst case scenario to pick and place the bomb somewhere for containment and for repeated pick and place action in industries. Hence, it is proposed to develop something that breaks the barriers and brings the digital world closer to the human world using accelerometers, gestures (flex sensors), advanced controller (avr328), latest wireless communication technology etc. The main objective behind this project is to make a robotic arm that would imitate the gestures of a human arm. The developed system has three parts. One, Haptic Glove Side Unit, second is Robotic Arm Side Unit and the third part constitutes the Mechanical Assembly of Arm. The Haptic Gloves comprises of Atmega 328 microcontroller, ADXL335 MEMS Accelerometer, Flex Sensor, Potentiometers, LCD display and Zigbee transceiver. The Robotic Arm Side Unit consists another Atmega 328 microcontroller, Zigbee transceiver and LCD display and servo-motors and mechanical assembly of arm with gripper. The intelligent control functionality is obtained by the embedded software which has been developed for both microcontrollers. The programs are developed by using Arduino IDE.

2. **RELATED WORK [LITERATURE SURVEY]**

The review of literature survey has revealed very interesting facts about the robotic arm. Many people have worked on this topic by adapting very different approaches. Some researchers have used wired communication methodologies and some have adapted wireless communication methods. Even while selecting the sensors, it has been noted that a variety of sensors have been implemented in design and development of robotic arm.
Abidhusain Syed et al. suggests the application of flex sensor for robotic arm control using P89v51RD2 microcontroller, data glove, analog to digital converter, position control system and degree of freedom. This is a wired application [1]. Shimshree Verma et al. suggests the use of Arduino board, Gyroscope, Accelerometer, servo motors and APC-220 a wireless RF communication module in design and development of gesture remote control robotic arm [2]. Shivani et al. reports the application of gesture sensor, arduino board, accelerometer, servo motors for implementation of wired gesture controlled robotic arm [3]. Vivek Bhojak et al. implemented the gesture controlled mobile robotic arm using accelerometer, gesture, servomotors, AVR controller, gripper etc. He adapts the RF transceiver for wireless communication [4]. Malav Atul Doshi et al. reports the use of robotic hand with real time control, which is very cost-effective. This robotic arm consists of five fingered palm which mimics a small degree of dexterity and could be used for other applications such as prosthesis for leprosy patients. This will allow them to get a higher degree of freedom [5]. Tejashree Dhamapurkar et al. discusses the design and implementation of a wireless animatronic hand using XBee-S2 and Arduino-UNO board. She also highlights the use of wireless communication and its applications by using wireless animatronic hand. The system is developed by using control glove, micro servo motors, XBee-S2 and Arduino-UNO board having on-board Atmega-328 [6]. Premangshu Chanda et al. suggest the design and implementation of a wireless gesture controlled Robot using Arduino ATMEGA32 processor and an Android operated application to control the gestures via Bluetooth wireless connectivity. The system has two components: The Hardware part consisting of Arduino Microcontroller, the Adafruit motor Shield, HC-05 Bluetooth module, and the Android Smart phone, and the software part consists of a Java based application run on android [7]. Rakesh H K et al. reports the application of Gesture Controlled robot which can be controlled by hand motions. It requires wearing a transmitting gadget and it will transmit orders to the robot which performs the actions. The transmitting unit has an ADC which converts the analog data into digital data and sends to microcontroller IC which is use to encode the four piece information and after that it will transmit by a ZigBee Transmitter module. The ZigBee Receiver module gets the information and translates it by microcontroller. Lastly system attempts to control the robot either to move forward, backward and left or right etc. The receiving end has four motors are interfaced to the microcontroller. Two of them are used for arm and gripper movement of the robot while the other two are for the body movement of the vehicle. The android application device transmitter acts as a remote control that has the advantage of adequate range, while the receiver end Bluetooth device is connected to the microcontroller to drive DC motors via motor driver IC for necessary operation. Remote operation is achieved by any smartphone/Tablet etc., with Android OS; upon a GUI (Graphical User Interface) based touch screen operation [9]. Pravin Vaishnav et al. suggest a model for gesture controlled user interface (GCUI). He also present an integrated approach is real time detections, gesture based data which control vehicle movement and manipulation on gesture of the user using hand movements. A three axis accelerometer is used. As the person moves their hand, the accelerometer also moves accordingly. The gesture is capture by accelerometer and processed by gesture. It also proposed utility in field of construction, medical science and hazardous waste disposal [10]. This proposed system is not only uses a wireless communication technology such as Zigbee,
but also high end microcontroller AVR328 along with arduino platform and precision accelerometers, flex sensors and rover platform to carry robotic arm wirelessly.

3. THE SYSTEM OUTLINE

The proposed system is based on ATMEGA 328 AVR RISC family of microcontroller for monitoring and control of Rover and Robotic ARM. The system has two major units 1. Remote Control Unit (Hand Gesture) and 2. Receiver Unit (Rover & Robotic ARM assembly). The Remote control unit (Hand gesture) consists of various sensors like flex sensor, MEMS accelerometer and some potentiometers. The Receiver unit/Rover unit consists of a movable rover platform on which Robotic ARM assembly is fixed. The wireless connectivity is attained by using Zigbee wireless communication module. Both units are rechargeable battery operated. Any movement in the hand gesture is replicated in the ARM assembly. For rover movement in all four directions two geared DC motors are used while Arm movement is achieved by using 5 servo motors. The software programming is done by using Arduino Uno platform. The gripper has the capacity to lift the load of approximately 150 gm. The system is customized for low power operation as it is operated on rechargeable batteries.

4. METHODS AND MATERIALS

The complete system block diagram of the developed system is divided into two parts. The first part is Transmitter unit (Remote Control Unit/Hand Gesture) and the second part is Rover (Receiver) unit. The transmitter unit is a wireless hand held unit which is used to control the movement of Rover (Receiver) & robotic ARM. The rover unit is also a wireless mobile platform on the top of which mechanical robotic arm assembly is fixed. The various blocks of these two units are briefly explained as below.

The Remote Control Unit: This hand held wireless unit has the following major blocks, some of important blocks are briefly explained as follows:

- ATMEGA 328 Microcontroller
- Hand Gesture Module: It consists of three sub systems
  - MEMS 3-Axis Accelerometer
  - Flex Sensor
  - Potentiometers
- LCD Display Unit
- Wireless Communication Module ZIGBEE Transceiver
- Battery Power supply Unit

![Figure 1](http://www.iaeme.com/IJMET/index.asp) Functional Block Diagram of the Transmitter (Hand Gesture) Unit
ATMEGA 328 AVR RISC Microcontrollers: The microcontroller is the most important unit of this system which controls all the functionalities. A microcontroller is a single chip computer that contains the processor (the cpu), non-volatile memory for the program (Rom or Flash), volatile memory for data input and output (ram), a clock and an i/o control unit, also called a "computer on a chip." Billions of microcontroller units (MCUs) are embedded each year in a myriad of products from toys to appliances to automobiles. It is a single chip microcontroller created by Atmel and belongs to the megaAVR series. This microcontroller combines 32 KB ISP flash memory with read-while-write capabilities. There are two microcontrollers in this project, one in Remote Control Unit side (Haptic/Hand Gesture module) and another in Rover unit side. In Remote Control Unit, the microcontroller controls Hand Gesture/Haptic (MEMS 3-axis accelerometers, flex sensors, potentiometer), LCD display and Zigbee transceiver and the other microcontroller in Rover Unit side controls Zigbee transceiver, LCD display and Servo Motors, DC motors etc.

Hand Gesture (Heptics) Module: Heptics is the science of applying touch sensation and control for interaction with virtual or physical applications. The word haptic is derived from the Greek word haptikos which means pertaining to the sense of touch. Haptics is one of the growing areas in human computer collaboration which deals with sensory interaction with computers. Haptic is used in engineering systems to create virtual environment. Gesture recognition is a topic in computer science and language technology with the goal of interpreting human gestures via mathematical algorithms. Gestures can originate from any bodily motion or state but commonly originate from the face or hand. Current focuses in the field include emotion recognition from face and hand gesture recognition. Many approaches have been made using cameras and computer vision algorithms to interpret sign language. However, the identification and recognition of posture, gait, proxemics, and human behaviors is also the subject of gesture recognition techniques.

Gesture recognition enables humans to communicate with Human Machine Interaction (HMI) and interact naturally without any mechanical devices. Using the concept of gesture recognition, it is possible to point a finger at the computer screen so that the cursor will move accordingly. The proposed hand gesture used in this work includes sensors like flex sensors, accelerometer and some potentiometers.

Three-Axis MEMS Accelerometer: MEMS stands for Micro Electro Mechanical Sensor. MEMS accelerometers are one of the simplest but also most applicable micro-electromechanical systems. ADXL335 is a MEMS based accelerometer that measures acceleration forces. These forces may be static, like the constant force of gravity pulling at your feet, or they could be dynamic - caused by moving or vibrating the accelerometer. The 3-axis accelerometer outputs three analog values corresponding to the X, Y & Z proportional to the tilt direction coordinates. By sensing the amount of dynamic acceleration, we can analyze the way the device is moving. These voltages are fed to ADC part of the microcontroller. The microcontroller routinely checks the outputs of the accelerometer and obtains the values tilt in each direction. The advantage of the accelerometer was that the values do not change unless there is a change in position.
Flex sensors: Flex sensors are sensors that change in resistance depending how much the sensor is bend. These sensors convert the change in bend to electrical resistance. The more the sensor bends, the higher is the resistance value. They are usually in the form of a thin strip from 1”-5” long that vary in resistance from approximately 10 to 50 kilo ohms.

Potentiometers: A potentiometer, informally a pot, is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. Potentiometers consist of a resistive element, a sliding contact (wiper) that moves along the element, making electrical contact with one part of it. Potentiometers operated by a mechanism can be used as position transducers. There is a direct relationship between slider position and resistance. In this project, we have used two potentiometers, one for sensing ankle joint and the other for sensing shoulder joint position.

ZigBee Technology: ZigBee is a technology based on IEEE 802.15.4 that provides users with a cost-effective standard with the ability to run for months or years on inexpensive primary batteries for typical applications. ZigBee devices operate in unlicensed bands of 2.4 GHz. At this frequency, 16 channels are available with a throughput rate of 250 kbps. The range of
ZigBee can extend from 10 to 75 meters and is dependent on the power output of the devices and the environment of the coverage area. ZigBee achieves its attractive low power consumption because of the low duty cycle expected for battery powered nodes within a ZigBee network. Once a node is associated with a network, it can wake up, communicate with other ZigBee devices and return to sleep. The longer the time in sleep, the lower the average power consumption. This module is used for establishing the wireless communication of the proposed system.

The Rover (Receiver) Unit: This is main unit of the proposed project, it consists of following parts:

- ATMEGA 328 Microcontroller
- LCD Display
- ZIGBEE wireless communication module
- Servo Motor driver circuit
- H-Bridge DC Motor driver circuit
- Rover assembly
- Mechanical ARM assembly
- Rechargeable 12v DC Power Supply Unit

Some of the important parts of these units are discussed briefly as under:

**Figure 5** Functional Block diagram of the Receiver (Rover) Unit

**Servo Motors:** Servo motors are a type of electromechanical actuators that do not rotate continuously like DC/AC or stepper motors; rather, they are used to position and hold some object. They are used where continuous rotation is not required so they are not used to drive wheels (unless a servo is modified). In contrast they are used where something is needed to move to particular position and then stopped and hold there. Most common use is to position the rudder of aircrafts, robotic arm and boats etc. The servo can be commanded to rotate to a particular angle (say 30) and then hold its position there. Servos employ a feedback mechanism, so it can sense an error in its positioning and correct it. This is called servomechanism. Suppose if we ask servo to go and lock itself to 30 degrees and then try to...
rotate it with your hand, the servo will try hard and its best to overcome the force and keep servo locked in its specified angle. Controlling a servo is easy by using a microcontroller, a control signal is needed to be feed to the servo to position it in any specified angle. The frequency of the control signal is 50 Hz (i.e. the period is 20ms) and the width of positive pulse controls the angle. We use the Atmega 328 microcontroller’s PWM feature to control servo motors.

**H-bridge DC motor driver:** H-bridge, sometimes called a "full bridge" the H-bridge is so named because it has four switching elements at the "corners" of the H and the motor forms the cross bar. They are the bones of many robotics hobbyists. The four switching elements within the bridge are often called, high side left, high side right, low side right, and low side left. The switches are turned on in pairs, either high left and lower right, or lower left and high right, but never both switches on the same side of the bridge. If both switches on one side of a bridge are turned on it creates a short circuit between the battery plus and battery minus terminals. This phenomenon is called shoot through in the Switch-Mode Power Supply (SMPS). If the bridge is sufficiently powerful it will absorb that load and your batteries will simply drain quickly. Such H-bridge driver circuit is used to drive two geared DC motors for rover assembly.

**Rover Assembly:** Rover assembly is nothing but a wirelessly moving platform on the top of which mechanical ARM assembly along with battery & electronics circuit board is fixed. There are many types of rover assembly depending upon the requirement of applications such as two wheeled rover, multi-wheeled rover, platform less rover etc. The following fig 6 shows geometry of the developed rover. In this proposed project we have used 3-wheeled rover.

![Figure 6](image-url)

**Figure 6** Geometry of Rover platform (solid edge drawing)

This rover assembly consists of a fiber platform fitted with two geared DC motors with tracker wheels rear side and a caster wheel on to the front side. The movements of rear wheels are controlled by H-bridge driver circuit in any four direction with respect to which the front caster wheel makes the movement. The geometry of this rover is as shown in above fig with dimensions. The platform also fitted with arm assembly, microcontroller, zigbee transceiver and steering control. The robot vehicle could control basic functions such as movement in forward, backward, left, and right directions. Besides, the gripper arm can be moved up or down and the jaws can be closed or opened to grab or drop an object. Robot arms are often categorized by their degrees of freedom.

**Robotic ARM Assembly:** Robotics arm assembly consists of complete replication of human arm. This work is concerned with fundamentals of robotic arm, including kinematics, dynamics.

**Components and Structure of Robots:** Robot regulators are consists of links connected by joints into a kinematic chain. Joints are of rotary (revolute) or linear (prismatic) types. A revolute joint is like a hinge and allows relative rotation between two links. A prismatic joint...
allows a linear relative motion between two links. We use the convention \( R \) for representing revolute joints and \( P \) for prismatic joints and draw them as shown in Figure 7.

![Figure 7 Symbolic representation of robot joints.](image)

Each joint related to the interconnection between two links, say \( i \) and \( i+1 \). It can be denoted by axis of rotation of a revolute joint, or the axis along which a prismatic joint slides by \( z_i \) if the joint is the interconnection of links \( i \) and \( i + 1 \). The joint variables, denoted by \( \theta_i \) for a revolute joint and \( d_i \) for the prismatic joint, represent the relative displacement between adjacent links.

**Degrees of Freedom and Workspace:** The number of joints determines the degrees-of-freedom (DOF) of the manipulator or regulator. Typically, a manipulator should possess at least six independent DOF: three for positioning and three for orientation. With fewer than six DOF the arm cannot reach every point in its work environment with arbitrary orientation. In certain applications such as reaching around or behind obstacles require more than six DOF. The difficulty of controlling a manipulator increases rapidly with the number of links. A manipulator having more than six links is referred to as a kinematically redundant manipulator. The workspace of a manipulator is the total volume swept out by the end-effector as the manipulator executes all possible motions. The workspace is constrained by the geometry of the manipulator as well as mechanical constraints on the joints. For example, a revolute joint may be limited to less than a full 360° of motion. The workspace is often broken down into a reachable workspace and a dextrous workspace. The reachable workspace is the entire set of points reachable by the manipulator, whereas the dextrous workspace consists of those points that the manipulator can reach with an arbitrary orientation of the end-effector. Obviously the dextrous workspace is a subset of the reachable workspace.

**General structure of Robotic ARM:** A Robotic Arm is a robot manipulator, usually programmable, with similar functions to a human arm. The links of such a manipulator are connected by joints allowing either rotational motion (such as in an articulated robot) or translational (linear) displacement. The links of the manipulator can be considered to form a kinematics chain. The end of the manipulator is called the end effectors and it is analogous to the human hand. The end effectors can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. The robot arms can be autonomous or controlled manually and can be used to perform a variety of tasks with great accuracy. The robotic arm can be fixed or mobile (i.e. wheeled) and can be designed for industrial or home applications. The following fig shows general structure of robotic ARM.
Functioning of Robotic Arm: A small object of low weight is placed near the robotic arm at a distance within the approach of arm. The system is made on. The operator stands at a distance from the robot and moves the finger/hand up, down, left or right. The robotic arm follows the direction. The arm is brought over the object and then lowered. The gripper is fully opened to pick up the object. The robotic arm then is moved up and rotated to another desired position, then lowered. When the arm reaches the floor, the gripper is given a command to release the object, which places it at the desired location. This way the robotic arm can be operated and controlled in any manner as deemed necessary by the operator from a distance, usually up to 200 meters.

5. SYSTEM OPERATION
The system operation can be performed by the following sequence of steps.

- Switch ON the hand held remote control unit and position the rover platform near to the object.
- A small object of low weight is placed near the robotic arm at a distance within the approach of arm.
- There are three sensors to create movement in the robotic arm such as accelerometer, flex sensor (gesture glove) and some potentiometers.
- The operator stands at a distance from the robot and moves the finger/hand up, down, left or right.
- The arm is brought over the object and then lowered.
- The gripper is fully opened to pick up the object.
- The robotic arm then is moved up and rotated to another desired position, then lowered.
- When the arm reaches the ground floor, the grabber is given a command to release the object, which places it at the desired location.
- This way the robotic arm can be operated and controlled in any manner as deemed necessary by the operator from a distance, usually up to 100 meters wirelessly.

6. EXPERIMENTAL RESULTS & DISCUSSIONS
The designed system is very rigorously tested in the laboratory, any movement in the hand gesture will be replicated Arm assembly. The designed module is based on the Zigbee wireless communication, hence, the operating range is limited to around 75 ft. The lift capacity of the gripper is around 150 gm. Precautions have been taken to reduce the weight of the rover and arm assembly, as the system works on rechargeable batteries. The developed
system showed the precise movement of rover and the arm. The actual photograph of the remote control (Hand gesture) unit and rover unit is shown in fig.

![Remote Control (Hand Gesture) Unit and Rover Unit](image)

**Figure 9** Actual photograph of Remote Control (Hand Gesture) Unit and Rover Unit.

### 7. CONCLUSIONS

The objectives of this work has been achieved which was developing the hardware and software for an accelerometer and flex sensor based wirelessly controlled robotic arm which wirelessly moves robot arm and works according to your hand gesture. The robotic arm has been developed successfully as the movement of the robot can be controlled precisely. Microcontroller programming is done to drive the serve motor for wireless control of the robotic arm by employing zigbee wireless application protocol. The zigbee transceiver module is working on the ISM band frequency of 2.4 GHz and has a range of 50-80 meters. A gripper will allow the movements of the palm and allow picking and placing of objects.

This system has functioned reliably and the trials have been carried out with acceptable results. It was rigorously tested for its proper operation and reliability. From observations, during trials, it was found that its movement is precise, accurate. This prototype device is easy to use and user friendly. In fact, the device, despite having several functionalities, has acceptable dimensions.

This robotic arm control is expected to overcome the problem such as placing or picking object that away from the user, pick and place hazardous object in a very fast and easy manner.

### REFERENCES


