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Design and Development of Bomb Defusing Robot Controlled by Gesture

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Abstract

Neutralizing explosives is one of precision and accuracy tasks handled by law enforcement personnel; it can be error-prone and life threatening. This paper seeks to demonstrate an improved use of remote controlled robots for Explosive Ordinance Disposal (EOD) using gesture manipulation. There exist a variety of EOD robots capable of handling different types of Explosives. This work is concerned with a class of EOD that uses the principle of wireless transmission of data packets within the ISM 2.4GHz spectrum, electrical H-Bridge circuits, servo-mechanisms and potential division in its underlying architecture and operation. The class is a fully integrated and non-autonomous system used by Law Enforcement Agents as First Responders. The developed EOD robot possesses two arms for gripping and manipulation. The robot arms are controlled by inputting commands on a handheld remote control or by human arm gesticulation. For gesture control, flexing the index finger closes the arm's gripper, flexing the thumb moves the wheels forward and backward, tilting the back of the controlling hand tilts the robot's elbow and rotating the wrist controls the waist.

Keywords: Explosive Ordinance Disposal; Gesture Control; Remote Control; Robot.

1. Introduction

Advancement in Mobile Robotics has allowed the penetration of more robots into practical field service. The two most active application areas for mobile robots so far have been military and law enforcement. For law enforcement, most activities to date have been in the area of explosive ordnance disposal (EOD), where robots are used to keep the human bomb disposal expert away from life threatening risk.

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In 1999, the National Institute of Justice (NIJ) funded the Battelle Memorial Institute to perform a survey on the desired attributes of an EOD robot. In addition, NIJ funded the Space and NavalWarfare Systems Center, San Diego (SSC San Diego), to assess law enforcement needs for robots beyond EOD and identify technologies from Department of Defense (DoD) robotics projects that can help meet those needs [1].

The demand for these kinds of devices sprouted during and after World War 2. There are commercial and Off-The-Shelf Disposal Robots with maneuverable arm and camera system which can function on all terrains. In selecting a bomb defusing robot, one considers factors such as the type of explosive to be disarmed, the operating terrain, operation range, manipulators, cost and so on.

In order to carry out their tasks, a robot may make use of all or some of the following: effectors / manipulators such as claws/grippers, cutters, suction cups, tools to ward off obstacles, motorized saw, weapons and utilities like tear gas and flame extinguishers. For movement, few robots implement 4 to 6 wheels and tank wheels.

2. Literature Review

In [2], the authors provided a report focused on the application of gesture control and robotics to aid the physically challenged. The main tool that was used in the work was an Android device due to the availability of an in-built accelerometer and Bluetooth technologies. It also made use of the Zigbee RF module, the HC-05 Bluetooth module, flex potentiometers and H-Bridge Motor Driving Circuit. The two-wheeled robot would be made to move forward, backward, left and right due to the flex sensors attached to the control glove which sense the tilting of the fingers and pressure applied during flexion. These analog data would then be computed by the processing unit of the Arduino nano board which in turn manifests those motions on the wheels with the driver logic. The report emphasized the use of the Android device for a cost effective accelerometer, and RF transceiver.

The work by [3] focuses on the use of gesture control in robotic for the physically challenged. The robot would be controlled by gestures from the tilting of the human hand. Tilt forward to go forward, tilt backward to go backward, tilt left to go left and right to go right. The motivation for their work came from the experience they had watching an individual struggling to move his wheelchair with great difficulty. Perhaps an interesting thing to note in their implementation was the use of the HT12E and HT12D encoding and decoding Integrated Circuits respectively which were used for error detection and correction before passing the transmitted data onto the RF Transmitter or receiving transmitted data from the RF Receiver. The ADXL335 Accelerometer was used for acceleration measurements and their transmitter and receiver operated on the band of 434MHz with a range of 50 to 80 meters.

The authors in [4] presented the design and implementation of a universal systematic 2-dimensional terrain marking and coverage solution. They proposed a solution which builds up on two graph traversal algorithms; Depth First Search (DFS) and Breadth First Search (BFS), where the algorithms are adapted and modified to be utilized for coverage of 2-dimensional isometric grid-like representations of terrains. The solution is developed allowed each robot in the swarm to be fully capable of covering and marking any terrain by itself. This approach was optimized for higher efficiency by increasing the swarm size. The robots shared data in their path planning and self-organization within the terrain. Communication between robots enhanced their collaboration as a whole. However,robots' abilities are limited because a robot can see and move only to locations that are adjacent to its current location. The simulation results show that the simulated robot swarm systems are suited for efficient flat area coverage, allowing for redundancy in data collection, and tolerating individual robot errors and shortcomings as the number of robots becomes more abundant.

In [5], a cost effective bomb defusing Robot with live streaming dual camera interface integrated with Gas and Flame Sensors to aid in the bomb detection capabilities was developed. The implemented robot features a robotic arm with 4 degrees of freedom which can pick and carry any sophisticated object (up to 5kg) very precisely and smoothly. The body and the arm of the robot were custom designed and built with Aluminum alloy. The robot also streams video footage and can be controlled by a local web server.

In this paper an improved use of remote controlled robots for Explosive Ordinance Disposal (EOD) using gesture manipulation is discussed. The system features robotic arms with 4 degrees of freedom. In the work, an ESP32CAM board is used for recording video footage and streaming it to a local web server which is accessible by a browser with the IP address 192.168.4.1. The system also utilized an MPU 6050 3-axis accelerometer and NRF24L01+ transceiver module on the robot and the remote controller and each glove. All packets are sent and received using the 2.4GHz band within the range of about 800 meters.

3. Components of the Robot

3.1. L298N Motor Driver

A dual H-Bridge motor driver that performs speed and direction control of two DC motors at the same time is the L298N. This module can drive DC motors with voltages between 5 and 35V and a peak current up to 2A. To power an Arduino board, an onboard 5V regulator is enabled and a 5V pin is used as output provided the motor supply voltage is not greater than 12V. The 2V drop by the module is also taken into consideration. So the voltage at motors terminals will be 2V less the motor supply voltage.

This 6-pin module has two voltage rails - 5V to power the circuitry and 5 to 35V to power the motors connected. The H-bridge MOSFET transistors arrangement has the motor to be controlled at the middle. Depending on the direction of the current flow the DC motor can either rotate in clockwise or counter-clockwise directions. The Module uses 4 pins (In1,In2, In3 and In4) to control direction and 2 pins (EnA and EnB) to control speed through PWM outputs.Each of this motor driver module is capable of driving four DC motors each with operating voltage ranging from 3 to 12 V and current ranging from 40 to 180mA. It has only two slots for motor connections so two out of the four DC motors will be connected in parallel with each other. Figure 1 shows how to interface the Motor Driver with the Arduino Uno

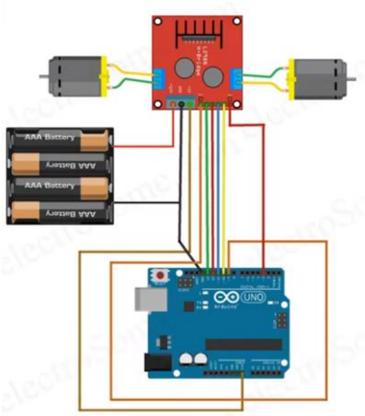

Figure 1: Interfacing the Motor Driver with the Arduino Uno [6]

3.2. NRF24L01+ Radio Frequency Module

It is a wireless transceiver module; it operates in the frequency of 2.4GHz ISM band and used for engineering applications. The module can cover a distance of 100 meters (200 feet) when used efficiently [7]. This module has a low voltage rating of about 3.3V and draws not greater than 12mA in working mode and less in idle mode. It features an on-board antenna which communicates serially with the Arduino through SPI (Serial Peripheral Interface). One module can offer up to 6 channels for communicating with other modules. Hence, a network formation is possible. Figure 2 shows the NRF Tranciever Module interfaced with the Arduino.

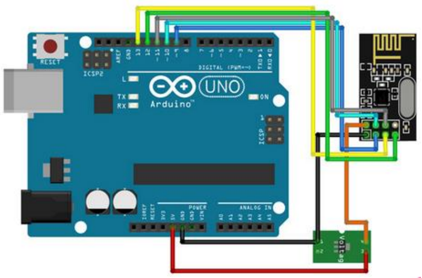

Figure 2: Interfacing the NRF Tranciever Module with the Arduino Uno [8]

3.3. AdaFruit Flex Sensor

Flex sensor can detect bending in one direction; it consists of resistors that change value based on how much they are flexed. The resistance increases with the degree of flex. The Flex Sensor is a potential divider; therefore the data to be collected on it is limited and fairly simple. It runs on a 5V supply and the amount of voltage dropped and current admitted depends on the degree of flex. The aim of using this is to determine thresholds of pressure during finger flexion and contraction. Those thresholds act as triggers which then move the robotic grippers. The interface between the Flex Sensor and the Arduino Uno is depicted in Figure 3.

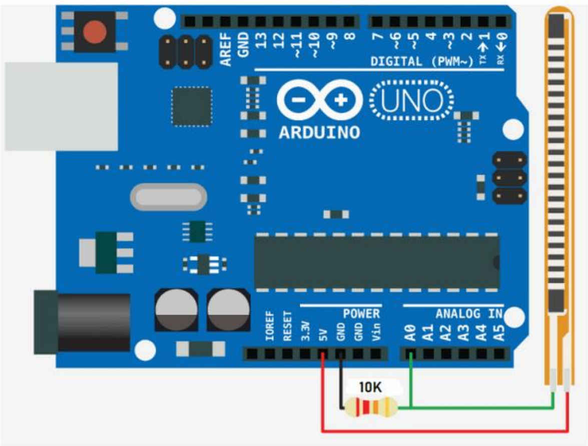

Figure 3: Interfacing the Flex Sensor with the Arduino Uno [9]

3.4. AdaFruit MPU6050 Accelerometer and Gyroscope Module

This sensor module has a 3-axis accelerometer and a 3-axis gyroscope. The gyroscope measures rotational velocity (rad/s) while the accelerometer measures acceleration (rate of change of the object's velocity). The MPU-6050 measures acceleration over the x, y, and z-axis. It can be used to measure changes in acceleration due to Earth's gravity, and angular velocity of moving objects. With the accelerometer's values, the roll and pitch angles can be computed using trigonometry. The objective here is to sense arm movements, so the Gyroscope values are ignored and the Accelerometer value are utilized.

3.5. Joystick Module and Potentiometer

The Joystick module and 10k potentiometer are different kinds of potential dividers; they can be employed in the implementation of a remote controller. The joystick is capable of measuring directions along its x and y axes because it slides a jockey over a metal plate of varied resistances. The Potentiometer does the same with the only difference being that it uses a knob to vary potential. Both can be interfaced with an Arduino and fed with a 5V power supply with the amount of voltage dropped being dependent on the length of the jockey slid across. The goal here is to determine thresholds of these particular values and use them to trigger the remote arm. With appropriate testing, the idle and trigger values were gotten and applied to the driving program. The Joystick Module and the Arduino Uno interface is shown in Figure 4.

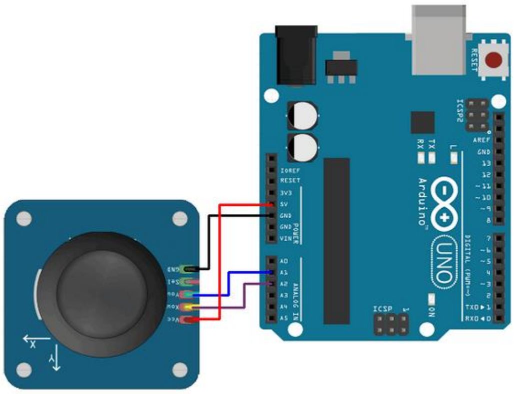

Figure 4: Interfacing analog Joystick Module with the Arduino Uno [10]

3.6. ESP32CAM Module

The ESP32-CAM is an inexpensive and easy-to-use microcontroller with an integrated video camera and microSD card socket. Its field of application includes Smart home devices, image upload and Wireless monitoring. Data Collection for the ESP32CAM Board is in the form of video streaming over a wireless network (Wifi). It is a 16 pin module which integrates a detachable camera lens along with Wifi, Bluetooth technologies, an on-chip Hall Sensor, Temperature Sensor and so on, all working with a 5V DC power supply and a current rating of 6mA. Programming the ESP32CAM Board did not come as easy as programming the Arduino because of the lack of an FTDI Port, therefore the need rose for an FTDI Programmer. Due to the absence of such, the Arduino Nano was then used as an FTDI Programmer to load the initialization code into the ESP32 board. The Board performs Serial Communication through UART so it contains Tx and Rx pins to be connected to the Tx and Rx pins of the Arduino Board respectively. Figure 5 shows an ESP32CAM Board interfaced with an Arduino Uno.

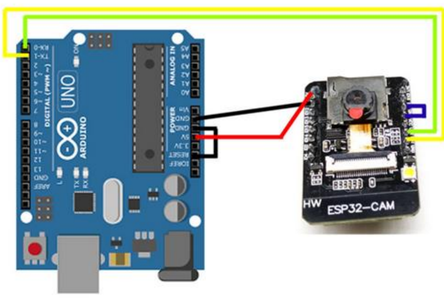

Figure 5: Interfacing ESP32CAM Module with Arduino Uno [11]

3.7. PCA9685 ServoDriver Module

Servomotors make up the joints of the robotic arms. This driver module makes possible the driving of up to 16 servomotors. The Arduino can drive at most 2 servos effectively, but for a greater efficiency and improved power characteristics, this module gives 16 channels along with an inlet for external power to drive the motors.

It serially communicates through I^2C and the data collected with the respective channel each servo was connected to. It is also worth noting that this module has two power sources : 5V to power its circuitry and 4.8 through 6V to power the servomotors individually. Its current ratings are 2.7mA (idle), 70mA (no load), 400mA (Stall). Figure 6 shows the connection of the servo driver module, the motors and the arduino uno.

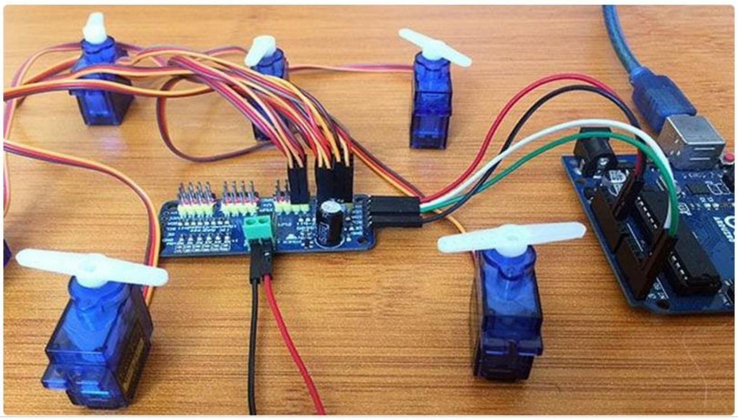

Figure 6: Wiring PCA9685 Servodriver module with an Arduino Uno [12]

The servomotors had the problem of jitter whenever they reached their extremes of rotation. In order to prevent this, operation is to be restricted to the minimum and maximum values of rotation.

3.8. Power Supply Design

3.8.1. Power Supply for the Robot

Desirably, the servos would work with current just a little above the no-load current rating (70mA), approximately 100mA. If there are 8 servomotors, it means

$$8 \times 100\ mA = 800\ mA \qquad (1)$$

This amount of current drained from the battery while in operation. If the servor is allowed to run for 5 hours before the battery dies, a 5V battery is needed with a capacity of

$$800\ mA \times 5 = 4000\ mA \qquad (2)$$

If 5V is to be supplied to the motors, compensating for the 2V drop given by the driver itself, the motors would be powered with a 7V DC power supply. At 5V the motors each consume about 71mA of current. Since there are 4 of them the total amount consumed will be

$$71\ mA \times 4 = 284\ mA \qquad (3)$$

If the motors are to run for 5 hours before the battery dies, a 7V battery is needed with a capacity of

$$284\ mA \times 5 = 1420\ mA \qquad (4)$$

All other modules on the robot were fed a 5V and 3.3V supply by the Arduino Uno board which was powered by a 9V battery.

3.8.2. Power supply for the remote and the glove controller

All potentiometers, joysticks and the NRF2401+ module were fed a 5V and 3.3V Supply from the Arduino Mega Board which was powered by a 9V battery. The glove controller modules on the robot were fed a 5V and 3.3V supply by the Arduino uno board which was powered by a 9V battery

4. System Block Diagram and Flowchart

4.1. Block Diagram of the Transmitter

The block diagram of the transmitter consists of the following blocks: Sensors: Accelerometer, Flex, Microcontroller Unit (ATMEGA328), Radio Frequency Transmitter, Potential Dividers and dc Power Supply (5V) as shown in Figure 7.

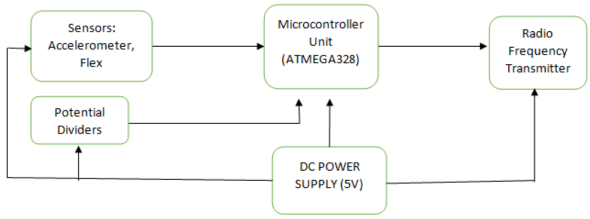

Figure 7: Block Diagram for the Transmitter

4.2. Block Diagram of the Receiver

The block diagram of the receiver is made up of the following blocks: Radio Frequency Receiver, Microcontroller Unit (ATMEGA328), dc Power Supply (5V), Robot Wheels and Robot Arms as shown in Figure 8.

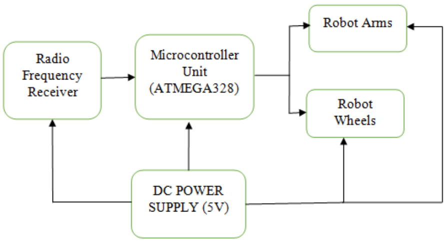

Figure 8: Block Diagram of the Receiver

4.3. Glove and Remote Controllers (Transmitters) Flowchart

The flowchart shows the program flow of the transmitter section.

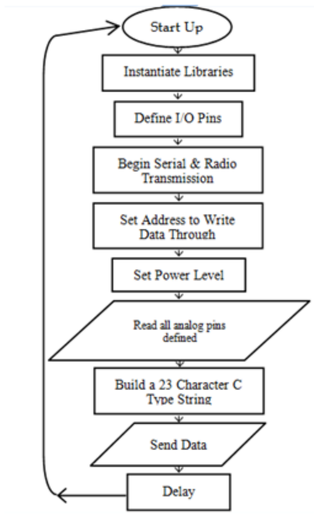

Figure 9: Flowchart for Transmitter

4.4. Robot (Receiver) Flowchart

The flowchart of Figure 10 shows the program flow of the receiver.

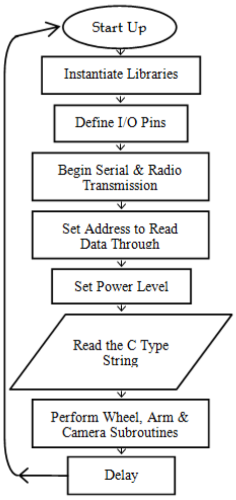

Figure 10: Flowchart for Receiver

5. System Implementation and Testing

The control program for this system was developed using Build and Fix Model. This involved alternating between writing code and debugging it until properly functioning program was obtained. For the Robot, the Arduino Uno was used, the remote controller, an Arduino Mega and the glove, an Arduino Nano. All codes were written in C++ and the Arduino Integrated Development Environment was used. After individual testing of various subsection, the subsections were integrated and tested wholly. The robot worked as expected.

5.1. The Flex Sensor

The flex sensor was interfaced with an Arduino Nano for the purpose of gesture control. As shown in figure 11-13 below, the digitized value of pressure sensed by the flex sensor increases and decreases when flexed in opposite directions. Ardiuno Nano is connected to the Flex sensor as shown in Figure 11; the set up is tested and the chart of the result captured as shown in Figures 12 and 13.

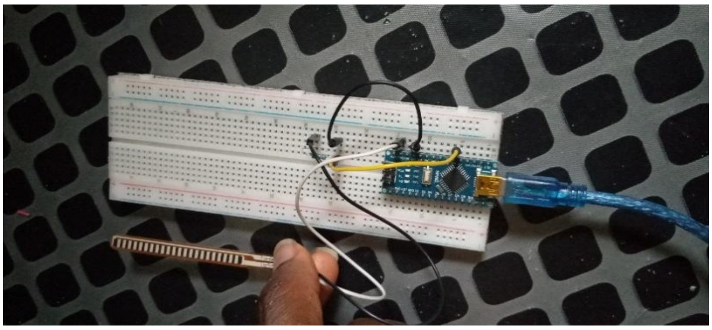

Figure 11: Interfacing Flex Sensor with Arduino Nano

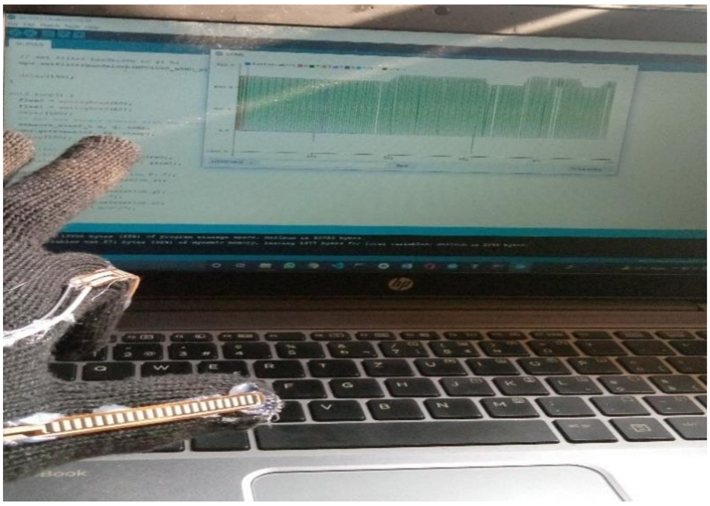

Figure 12: Testing the flex sensor

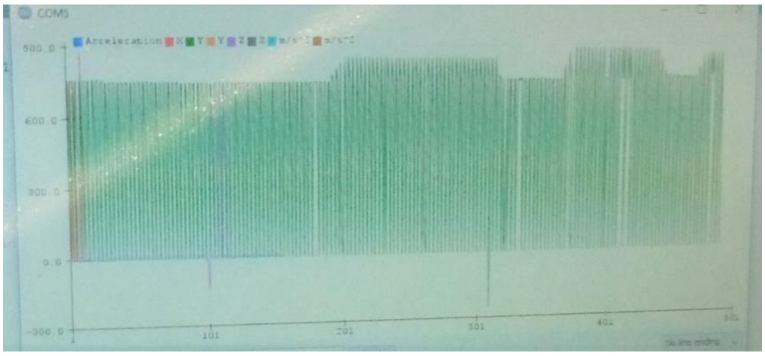

Figure 13: Chart showing the range of Operation of the Flex Sensor

5.2. The Accelerometer

The MPU-6050 Accelerometer/ Gyroscope was interfaced and tested with an Arduino Nano as depicted in Figure 14. It enables the rotation of the waist and elbow with controls from the glove. Figure 14 shows the interface of MPU-6050 Accelerometer with the Arduino Nano.

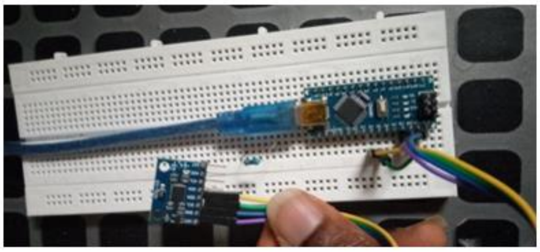

Figure 14: Interfacing the MPU-6050 Accelerometer with the Arduino Nano

A Serial Plotter was used to obtain the co-ordinates of the Accelerometer as captured in Figure 15. Serial plotter is a tool for tracking different data sent from arduino board. Go to your Arduino IDE, select "Tool" and from the drop down menu open "serial plotter".

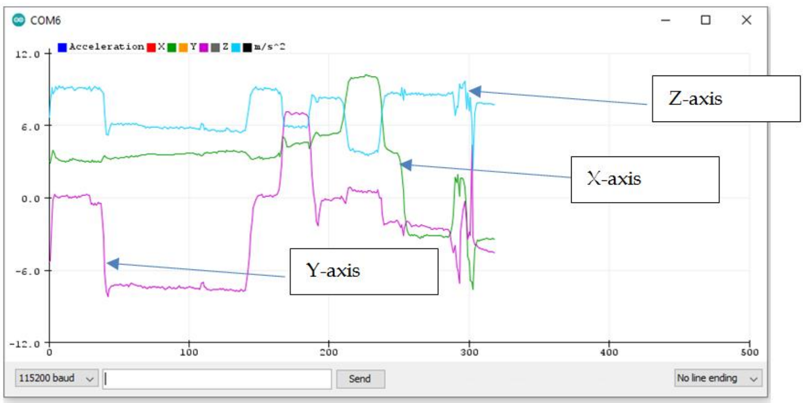

Figure 15: Co-ordinates from the Accelerometer seen from the Serial Plotter

5.3 The Joysticks and Potentiometers

As shown in Figure 16, the Joysticks and Potentiometer were interfaced with an Arduino Mega 2560 board. Moving the joystick and twisting the knob gave a range of values from 0 to 1023. The Arduino mega was chosen because of its abundance of analog pins. The analog pins were required for the remote.

Figure 16: Assembly of the joysticks and potentiometers

The Robot was finally implemented as captured in the picture of Figure 17.

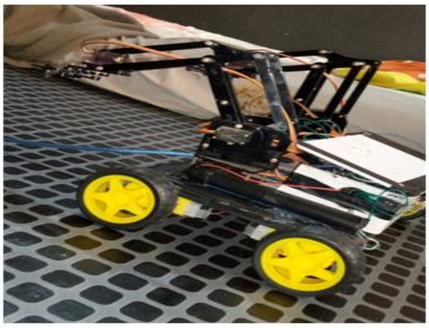

Figure 17: The Robot

6. Conclusion

In the course of this paper, the operational principles and design of a gesture controlled EOD robot was discussed. The system idea was conceived as a result of the need to use an unmanned and remote controlled vehicle to neutralize explosives and thus make safe the otherwise highly risky and life threatening job. The paper demonstrated the implementation of an improved use of remote controlled robots for Explosive Ordinance Disposal (EOD) using gesture manipulation. The EOD uses the principle of wireless transmission of data packets within the ISM 2.4GHz spectrum, electrical H-Bridge circuits, servo-mechanisms and potential division in its underlying architecture and operation.

The gesture controlled robot incorporates hand movements into control giving a more native and futuristic experience when disarming explosives. The robot developed was tested and conformed to be working appropriately. This device functions optimally in atmospheric temperatures range of 15^{o}c to 35^{o}c. Areas of use include wide open spaces, indoors and thicket. This work can be improved upon by; integrating an ultrasonic sensor for obstacle detection and avoidance; adding more cameras to give in-depth perception; using more number of wheels to improve maneuverability and increase traction, etc. Also a machine learning algorithm could be outsourced to give the robot a higher level of automation and make it able to recognize objects and act accordingly, while still being controlled (Semi-autonomous). This makes it artificially intelligent. Finally a larger battery capacity may be integrated and a stronger set of arms should be acquired for further work.

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