Gesture Controlled Robotic Arm For Hazardous Chemical Control

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***Abstract*— The use of nuclear energy is on the rise as it produces more power compared to fossil fuels and it does not produce greenhouse gas emissions such as carbon dioxide. However, it is very dangerous for humans and the environment when a nuclear meltdown happens. Nuclear waste takes a Jong time to decay and it releases radioactive in the process which is harmful to living things. A robotic arm can be used in these scenarios to move radioactive waste without human interaction. Operators can control the robotic arm wirelessly through gesture control from a safe distance without exposing them to radioactive. Gesture control is used as it enables the operator to live control the robot for different scenarios. The hand gesture-controlled robotic arm uses a wireless system to transmit data signals between the gesture controller and robot manipulator without any physical connection between the two systems. The wireless gesture controller will convey gesture movements from a real person's arm to control the robot manipulator. The proposed system uses flex sensors, ADXL335 accelerometers, and MPU6050 to capture hand gesture movements. Two Arduino Mega, one on the user's hand while the other on the robotic arm, and servo motors were used in the system. A pair of NRF24LOI+ transceiver modules are used to establish a wireless connection between the system.**

Keywords— ***Wireless, Robotic Arm, Flex Sensor, NRF24L01***

I. Introduction

The popularity of nuclear power is on the rise for years to come with the increased demand for power supplies. According to the World Nuclear Association, there is a total of 449 operable nuclear power plants worldwide which generates about 10% of the world's electricity in 2019. With around 30 countries in the world showing interest to emerge as a nuclear energy country, the number of nuclear power plants (NPP) will increase in the future. ln the year 2019, the World Nuclear Association recorded a total of 2676 billion kWh electricity generated by nuclear plants in the world with the United States of America (USA), France, and China.

There are several reasons for nuclear power to be included in the world energy solution despite having alternatives. Nuclear energy is produced through nuclear fission, which does not generate greenhouse gas emissions such as carbon that will contribute to global warming. It cont1ibutes toward decarbonizing and generates sufficient power at the same time when used to replace fossil fuel and natural gas. Next, NPP has higher reliability compared to other energy sources. The reliability of a power plant is determined by time. It generates energy, which is also known as the capacity factor. ln 2016, NPP in the USA recorded an average capacity factor of 92.3% while the other power plants such as hydroelectric, wind turbine, and solar power recorded only 38.2%, 34.5%, and 25. l% respectively (Rhodes and studies 2018).

However, the process of nuclear fission produces radiation along with useful energy. When exposed to a lethal amount of radiation, humans may suffer from acute radiation syndrome (ARS) which induces nausea, vomiting, and death in a worst-case scenario. Long-term radiation exposure also increases the chance of developing cancer in the human body (EPA 2019) (Kamiya, Ozasa et al. 20 15). According to the United States Nuclear Regulatory Commission, radiation produced by EPP are monitored before releasing into the environment to ensure there is no harm to its' surrounding. Unfortunately, such safety measures could not fully avoid radiation leakage as there have been more than 440 major radiations accidents with 5 major nuclear accidents rated level 5 and above on the International Nuclear and Radiological Event Scale (INES) recorded in the past. These events happened i11 Kyshtym (Russia (then USSR), 1957), Windscale Piles (the UK, 1957), Three Mile Island (the USA, 1979), Chernobyl (Ukraine (then USSR), 1986), and the most recent accident Fukushima (Japan, 2011). According to the research, most of the major nuclear accidents occurred when the NPP cooling system fails, causing a meltdown in the reactor and releasing radioactive materials into the environment (Kamiya, Ozasa et al. 20 15)..

Among the major nuclear accidents, two of them involve a major release of radioactive material and rated INES level 7. The first to be rated as such is the Chernobyl accident in 1986 and it is the worst nuclear accident in history. 134 workers out of 600 that took part in the emergency response have developed ARS due to the exposure to radiation and 28 of them passed away. During the Fukushima accident in 2011, Tokyo Electric Power Company (TEPCO) workers and contractors took on-site emergency work. Among these emergency and recovery workers, a total of 149 TEPCO workers and 24 contractors were exposed to more than 100 MSV of radiation, which potentially has an increased chance of developing cancer.

Robots have been put in commission to replace humans in performing dangerous tasks such as handling chemical products and radioactive materials. Several robots were used in the past to handle post-nuclear accidents. In the Three Mile Island accident, ROVER, LOUIE I, and LOUIE I1 were commissioned in the clean-up process with each robot performing g different task. Back in 1986, teleoperated robots STR-1 were sent in commission as an immediate response to the Chernobyl incident. The Fukushima accidents also saw many robots in action to assist with the post-accident recovery operation. According to Guizzo in 2011, a worker in the Fukushima-Daiichi NPP has written several blogs regarding his experience as the lead robot operator during the accident. iRobot has donated two Packbot 510 robots with hazmat kits, two Warrior 710 robots with manipulator arms ai1d training were given to Japanese operators by iRobot engineers to assist in the operation. Other robots such as JAEA-3 and PMORPH were also in action during the post-Fukushima accident (Guizzo 2011, Tsitsimpelis, Taylor et al. 2019).

II. Literature Review

A. Robotic Hand

Researchers (Krausz, Rorrer et al. 2015) proposed a six-degree-of-freedom (DOF) robotic hand that is designed and fabricated for testing purposes. Six DOF is chosen for the robotic hand as their movements are sufficient to perform standard pretension postures such as palmar, tip, and lateral pretension as well as the independent movement of each finger and thumb (Krausz, Rorrer et al. 2015). Similar research has been done and the design of their robotic hand is based on the open-source 6 DOF hand that is used by (Krausz, Rorrer et al. 2015) but some challenges were made to reduce cost and improve thumb mobility. The mechanism used by researchers (Krausz, RoJTer et al. 20 15) is mainly metal gears which are expensive while researchers (Sanchez-Velasco, Arias-Montiel et al. 2020) proposed to use acrylic made gears. It is lighter, cost cheaper, able to work under moderation vibration, shock, impact, and lesser wear and tear compared to metal. However, acrylic has disadvantages such as low strength and lower modulus of elasticity. By challenging the mechanisms, researchers (Sanchez-Velasco, Arias-Montiel et al. 2020) can reduce the cost by more than 90% (Sánchez-Velasco, Arias-Montiel et al. 2020).

Another research on robot hand is done by (Spadafora, Muzzupappa et al. 2015) for underwater applications. The proposed design consists of a palm and three independent fingers, each with 3 DO that is actuated by servomotors. This research aims to develop a prototype that can be used for grasping and manipulation operations in a submarine environment (Spadafora, Muzzupappa et al. 2015).

B. Robotic Arm

Research on 5 DOF robotic arms (RAVebots-1) is done by researchers (Roshanianfard and Noguchi 2018) to harvest heavy agricultural products. The proposed design is made up of revolute joints from the base frame to the end- effector. Solidworks is used to design, assemble and analyze the components used for the robotic arm. Mechanical formulas were used to analyze the dynamic components. The RAVebots-1's arm can cover a maximum frontal distance of 1640mm and a maximum height of 1430mm. It can move a maximum of 110° in the Z direction. The kinematics modeling of the proposed design is calculated by using Denavit-Hartenberg (D-H) parameter to forward and inverse kinematics.

Researchers (Mohammed and Sunar 2015) also discuss kinematics modeling of a robotic arm. Besides D-H convention method, the product of the exponentials (PE) method which is based on the screw theory is used by researchers (Mohammed and Sunar 2015) for the kinematics model of a 4 DOF robotic arm (RA-02). In comparison with the 5 DOF RAVebots-1 from researchers (Roshanianfard and Noguchi 20 18), the matrix of RA-02 expresses different equations but is somewhat similar.

C. Wireless Gesture Control

Researchers (Dhepekar and Adhav 2016) proposed a wireless control system using a flex sensor for a robotic hand. The proposed design has two sections, and the sensors are attached to a hand glove. In the transmitter section, the microcontroller (MCU) ATmega 328 will receive an input signal through the voltage divider circuit when the flex sensor is bend. MCU ATmega 328 is used because it has an inbuilt Analog-to-Digital converter (ADC). The MCU can be programmed to generate output depending on the input from the flex sensor. The converted signals are then sent to the Zigbee transmitter via a Universal Asynchronous Receiver-Transmitter (UART) port. The Zigbee is a device designed for wireless communication that transfers data over different networks. The Zigbee transmitter and receiver communicate with each other to transfer and receive signals for the MCU to control servo motors in the robotic hand. Servo motors move based on the Pulse Width Modulation (PWM) signal taken from the MCU and the robotic hand will move accordingly. The robotic hand's movement is determined by the bending of the flex sensor.

A similar method is proposed by researchers (Afzal, Iqbal et al. 2017) for a gesture control robotic arm. The robotic arm is controlled by using a hand glove that consists of flex sensors to control the finger movements and a triple-axis accelerometer for wrist and elbow movements. It is then made wireless by using a Zigbee transmitter-receiver module to enable operation from a distance. The analog output from the sensors is transmitted to the inbuilt ADC of the MCU Arduino UNO. The processed digital signal is then sent to the Zigbee transmitter module. The servos will move according to the digital data received by the Zigbee receiver module and mimic the hand movement of the user. Researchers (Afzal, Iqbal et al. 2017) mentioned that flex sensors are less sensitive and there is more internal and external interference. It also has an unpredictable value as it is a variable resistor.

Researchers (Salman, Cui et al. 2020) proposed a wireless-controlled robotic hand motion system with flex sensors. The system consists of two parts; a glove as the transmitter and a 3D printed forearm as the receiving end. A total of five flex sensors are attached to the glove to collect the actions of the hand's motion. These sensors transmit voltages through a resister division circuit to the master controller and process these inputs before sending them to the slave controller with a receiver module. The 3D printed fingers will move when the output of the slave controller commands the servo motors in the robotic hand. The control kernel used in the proposed design is Arduino Nano and NRF24LO I transceiver module. There are two Arduino Nanos, one as the master controller and the other as slave controller. The NRF24LOI transceiver module is used to create wireless communication between the two Arduino Nano.

A hand gesture control system using wireless sensor networks is proposed by researchers (Prabhu, Sreevidya et al. 2017) to control a robotic arm. The proposed system has two pai1s which are interconnected by wireless sensor communication systems. The first part is known as the transmitter where the control sensors are and the second part is the receiver where mechanical action takes place. X-Bee is used as the communication device between the two parts.

Researchers (Varghese and Thilagavathi 2015) proposed a wireless gesture-controlled anthropomorphic robotic arm. The robotic arm is designed to mimic the movements of a human hand by using a hand glove. Five linear slide potentiometers and a triple-axis accelerometer is attached to the hand glove to control the robot arm's movement. A Radio-Frequency (RF) transmitter-receiver module is used to make the system wireless to operate remotely.

One end of the slide potentiometer is fixed onto the glove while the other side is connected to a spring. When the glove is bent, the slider will be pulled towards the finger and move back to its original position when the tension is released. As potentiometer ai·e variable resistors, the resistai1ce value changes when the slider moves. The triple-axis accelerometer used is ADXL335. It can measure the static acceleration of gravity in tilt-sensing applications as well as dynamic acceleration resulting from motion, shock, or vibration (Varghese and Thilagavathi 2015). The wrist movement of the robotic arm is controlled by the movement along the x-axis and the y-axis controls the elbow movement. The RF modules work on the 433 MHz frequency band to transmit and receive signals to one another.

Researchers (Zain, Hassan et al. 2019) proposed a methodology to convert hand gestures into robotic hand movements. The proposed technique has two subparts, a transmitter and receiving section. The robotic glove which is the wireless controller of the system consists of an Arduino Nano, Flex sensors, and an RF Transmitter module. The Arduino Nano is programmed to process the Flex sensor's output according to the degree of bending based on the finger movement into data. The RF Transmitter module then receives the processed data and transmits them to the RF Receiver module in the robotic hand. The module constantly receives feedback from the hand and transmits new processed signals (Zain, Hassan et al. 2019).

The Receiving section of the system is the robotic hand. It consists of 8 servos that are connected in a way to provide 3 DOF to the system. 5 servos are used to control the finger movements, 2 servos for controlling wrist movements and the last servo is attached to the base of the system. An Arduino Mega is used to control the servo's movement by receiving signals from the RF receiver module. The system uses real-time hand gesture recognition and m1mJcs the glove movements worn by the user.

Researchers (Sihombing, Herriyance et al. 2020) used different approaches in controlling robot arms using hand gestures. In this research, (Sihombing, Herriyance et al. 2020) use a fuzzy logic method to process the input values from flex sensors and gyroscope to determine the movement of the human hand and fingers to control the robotic arm. A glove is used as the robot controller to place the sensors involved in controlling the robotic arm and the robotic model used in this research is a mechanical arm with a gripper.

The hand movement of the robotic arm is based on the degree of slope of the MPU-6050 gyroscope's x-axis and y-axis. Fuzzy logic uses these values to process the conditions for the robot's upper arm to move. The same fuzzy logic is also applied to the flex sensors on the index finger and middle finger of the robot controller to control the robot’s lower arm and wrist respectively. The gripper is controlled by a push-button using fuzzy logic with values **'I'** and 'O'. After processing the fuzzy logic values, the commands will be transmitted to the robot arm via Bluetooth.

Researchers (Karam, Al-Kadhimi et al. 2018) proposed the design and implementation of wireless controlled robotic hands to mimic the finger motion. The proposed design has two circuits, transmitting and receiving circuits. The transmitter circuit is attached to a glove along with flex sensors and the receiving circuit is connected to a robotic hand. Bluetooth modules HC-05 are used to communicate wirelessly between circuits and Arduino UNO processes the signals and controls the servomotor in the robotic hand. Each finger of the robotic hand is controlled by a servomotor and has a 3-DOF.

The movements of the fingers are derived mathematically using forward and inverse kinematics and MATLAB Simulink is used to simulate the robot kinematics. Physical tests of the proposed design show that the hand motion of the prototype can handle the objects concisely and has a maximum range of 37 meters for connectivity. For future enhancement, Node MCU module can be used to improve the wireless transmission distance and a close loop control algorithm can be implemented to further increase the finger motion's stability.

In this research, a wireless glove controller is used to control a robot hand via wireless transceiver module NRF24101. Flex sensors are used to obtain input data from the user's finger to control the servomotor movements in the robot hand. The data signals are then processed by Arduino NANO and transmitted through NRF24L01 from the transmitter circuit to the receiver circuit. Researchers (Bakri, Adnan et al. 20 19) have tested the connection strength between the transmitter and receiver circuit against the distance between them. The test has done on an open football field with fewer obstacles to avoid signal interference. Based on the test results, the connection strength of the NRF24LOI gets weaker as the distance increases. For a distance above 100 meters, the connection could not be established as it has exceeded the operating rai1ge of the transceiver module.

Researchers (Anughna, Ranjitha et al. 2020) proposed a wireless robotic model that uses flex and gyro sensor. The gyro-sensor that is used in this project is the MPU6050 sensor. It is a 6 DOF IMU sensor that has six different outputs, three from the accelerometer and three from the gyroscope. MPU6050 sensor uses I2C protocol to communicate with the Arduino Atmega328. The transmitter system reads data from the flex sensor and MPU6050 and then transmits the processed data signals to the receiver system via an RF module. The receiver system then processes the data signal to control the robot arm with a flex sensor controlling finger movements and MPU6050 controls wrist movement. It can be observed that the robot arm can move in six different positions as a human arm .

III. PROPOSED SYSTEM AND ITS OPERATIONS

Fig. 1 shows the overall block diagram of the wireless gesture-controlled robotic arm. The system consists of two parts, a wireless controller and a robotic arm. The wireless controller consists of flex sensors, 6 DOF IMU sensor MPU6050 and two ADXL335 accelerometers and is placed on the user’s finger, elbow, wrist, and shoulder respectively. The sensors will detect the user’s arm movement and transmit the data signals via transceiver module NRF24L01+ to the robotic arm. The Arduino Mega will then process the data signals received from the wireless controller and send PWM signals to power the robotic arm, hence replicating the arm movements of the user.

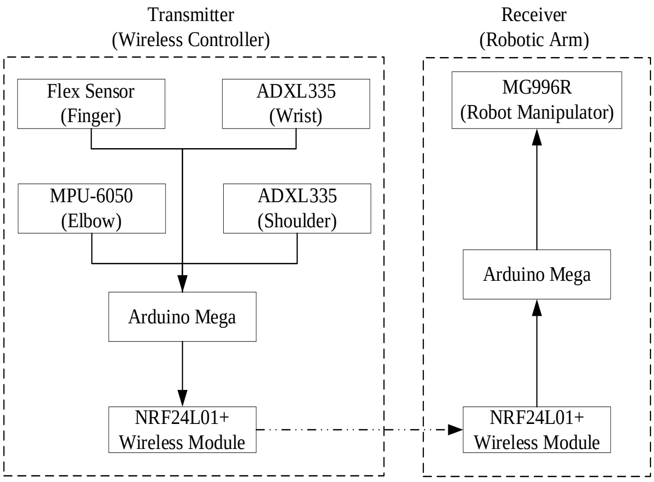

Fig. 1. General Block diagram

A. *Constructional Details*

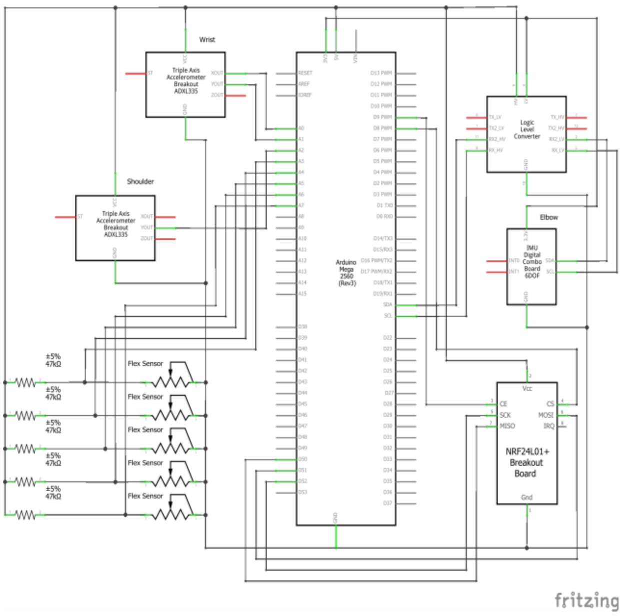

Fig.2. Constructional Diagram

Fig.2 shows the circuit diagram of the wireless controller. The wireless controller has three parts, which are the wrist, elbow, and shoulder that can be worn by the user to detect human arm motion. The wrist consists of an ADXL335 accelerometer and five flex sensors along with a voltage divider circuit while another ADXL335 is placed on the shoulder. The accelerometer outputs are connected to the analog pins of the Arduino Mega for the MCU to process raw data from the sensor as an input to control the robotic arm. The voltage divider circuit in the system is connected to the flex sensors to convert the output resistances into voltage. Fig. 3 shows the connection of the voltage divider circuit in the wireless controller.

The voltage divider circuit consists of a 47kΩ resistor connected in series with the flex sensor. The resistor is connected to the 5V power pin from the Arduino Mega while another end of the flex sensor is connected to the ground. This completes the voltage divider circuit and the V_{OUT} in between the resistor and flex sensor is connected to the Arduino Mega analog pin.

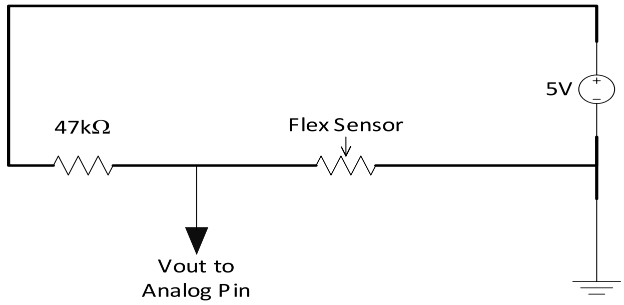

Fig. 3. Voltage divider Circuit Diagram

The MPU6050 is placed on the user's elbow. Instead of connecting the sensor to the analog pins, MPU6050 uses the I2C protocol to communicate with the MCU. I2C protocol transmits data between master and slave devices through Serial Data (SDA) pin and Serial Clock (SCL) pin. SDA is used to send and receive data between devices while SCL carries the clock signal. Fig. 4 shows the connection of MPU6050 to the Arduino Mega. MPU6050 sensor is a Micro-Electro-Mechanical System (MEMS) that consists of a 3-axis accelerometer, 3-axis gyroscope, and digital motion processor (DMP). It can be used to measure the acceleration, displacement, and motion-related parameters of an object. In this system, the embedded DMP in the MPU6050 is needed to calculate motion processing algorithms to provide motion data such as roll, pitch, and yaw angles.

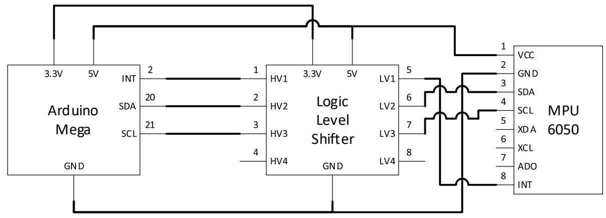

Fig. 4. MPU6050 Circuit Diagram

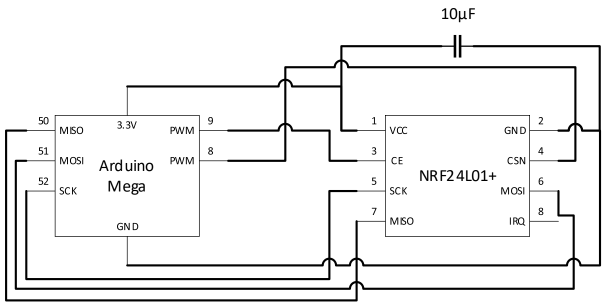

Fig.5. NRF24L01+ Circuit Diagram

It uses raw data from the gyroscope and accelerometer from the sensor to provide these motion data. MPU6050 is a sensor where its pins are powered on 3.3V. The VCC pin can be powered by 5V as it has a built-in voltage regulator. Since the output voltage of the pins on Arduino Mega is 5V, a logic level shifter is added to the circuit to prevent the MPU6050 breakout board from damaging. It is used to convert logic signals from one level to another. The level logic shifter used in the system is bi-directional and it can convert 5V signals to 3.3V and vice versa. HV represents high voltage as in 5V while LV represents low voltage as in 3.3V. When a 5V pin is connected to the HV pin, it will convert the logic signal into 3.3V at the LV pin. The Arduino Mega pins are connected to the HV pins on the logic level shifter while the MPU6050 pins are connected to the LV pins. This connects the SDA, SCL, and interrupt pin of the MPU6050 to the Arduino Mega without damaging the device.

Fig. 5 shows the circuit diagram of NRF24L01+ to the Arduino Mega. It is a transceiver module that can be programmed to send or receive data. The wireless module uses Serial Peripheral Interface (SPI) protocol to communicate with the MCU. The SPI bus used in this transceiver module has 5 signal pins, which are Master – Out / Slave – In (MOSI), Master – In / Slave – Out (MISO), Serial Clock (SCK), Chip Enable (CE), and Chip Select Not (CSN). In SPI communication, devices are connected in a Master-Slave relationship where the MCU is the Master bus and other devices are slaves. In this system, Arduino Mega is the Master bus that inputs data to the transceiver module which is the slave. The connection is established by connecting the MISO, MOSI, and SCK pin from NRF24L01+ to Arduino Mega digital pin 50, 51, and 52. MOSI and MISO are the input and output to and from the NRF24L01+ whereas SCK accepts clock pulses that are needed for SPI communication from the MCU. To enable SPI communication, the CE and CSN pins are connected to digital pin 8 and 9 of the Arduino Mega.

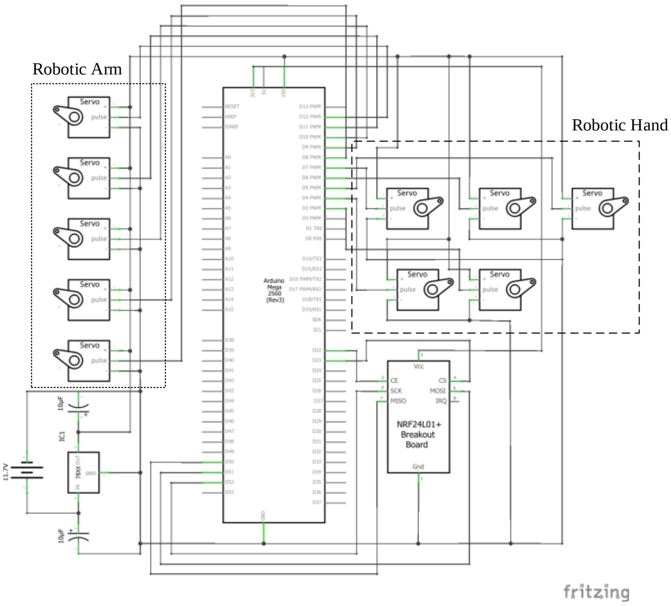

Fig 6. Circuit diagram for Robot manipulator

The transceiver module will be programmed to send or receive data depending on the mode that is selected through the CE pin. The CSN is an Active-Low pin that is usually kept high or the SPI communication will be disabled. When the CSN pin is low, the transceiver module will start listening to the SPI port for data to process. To protect the NRF24L01+ from damage, an adapter module with a voltage regulator is connected to the transceiver since it powers on 3.3V. As the system communicates wirelessly, there may be noises during data transmission. Hence, a 10μF capacitor is connected in parallel to the V_{CC} and GND pins of the NRF24L01+ to stabilize and filter out noises in the wireless connection.

Fig.6 shows the circuit diagram of the robot manipulator and it is similar to the design as proposed in Chapter 3. The robot manipulator has two parts, a robotic arm & hand. The robotic arm is a 6DOF mechanical robotic arm that is powered by five MG996R servo motors at each joint and the robotic hand has five LFD-01 servo motors to power each finger. As shown in Fig.6, the PWM pin of each servo motor is connected to the PWM digital pins of the Arduino Mega to control the robot manipulator's movement. The NRF24L01+ is connected in the same manner as shown in Fig.5.

B. *Working Principle*

Fig.7 shows the flowchart of the overall system. When the system is turned on, Arduino Mega on both circuits will initialize the sensors and transceiver modules. During the calibration stage, the devices must be stationary for sensor MPU6050 to calibrate their starting position. After calibration, the system is ready to acquire data from the sensors. When the sensor detects any movements, the output readings will change accordingly to the hand movements from the user. The output readings are then transmitted to the receiver circuit via NRF24L01+. On the receiver side, the transceiver module is on standby mode to receive data after initializing. The data signals received from the module will be processed into PWM signals to control servo motors in moving the robot manipulator. Both the circuits will run continuously in a loop until the power source is cut off.

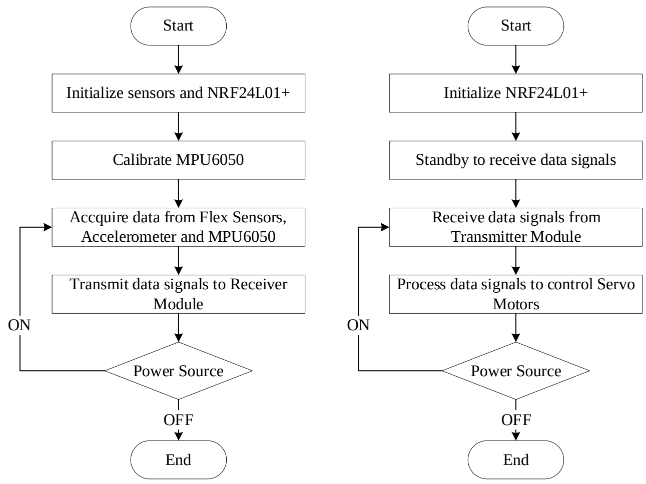

Fig 7. Flowchart of Wireless Gesture Controlled Robotic Arm

C. *Flex Sensor*

Flex sensor is a variable resistor that measures the deflection amount from its original position to determine the resistance value. When the carbon surface on the flex sensor is bent, the resistance value will change depending on the bending angle. Fig.8 shows the flex sensor bending conditions. The change in resistance of the flex sensor is directly proportional to the bending angle therefore the resistance value increases as the bending angle goes from flat to 45° to 90°. For the Arduino Mega to read the output values, a voltage divider circuit is used to convert the resistance value of the flex sensor into a voltage value. The wireless gesture controller utilizes the flex sensor's characteristics to control the robot hand's movement. The Arduino Mega is programmed to control servo motors on the robot hand according to the flex sensor's output. The flex sensors are placed on a glove for the user to wear. When the user bends its fingers, the flex sensor's bending angle will increase resulting in a change in the sensor output. This allows the servo motor to move and bend the robot arm's fingers thus mimicking the user's finger movement.

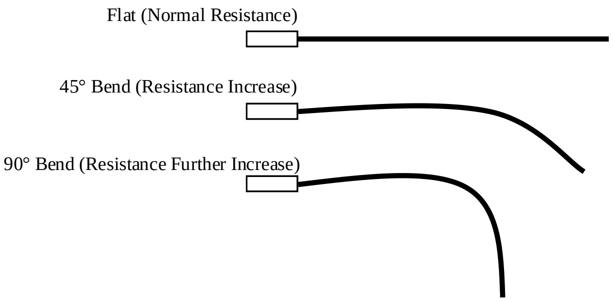

Fig 8. Fex sensor bending conditions

D. ADXL335 Accelerometer

The accelerometer is a device that measures acceleration in the form of analog inputs on the X, Y, and Z-axis. For ADXL335, acceleration is measured when the device has a change in direction. It is a MEMS device that has a suspended mass etched on a silicon wafer where the mass will deflect when force is applied to the device. As ADXL335 is an analog accelerometer, it is a capacitive sensing accelerometer. When the device moves in the 3-axis dimension, the capacitance will change hence changing the analog voltage sensed by the MCU. In this system, the ADXL335 is placed on the wrist and shoulder of the user. When the user lifts and twists their hand, the change in analog voltage will control the robot manipulator accordingly.

E. MPU6050 Sensor

MPU6050 is a 6DOF sensor that works on the MEMS principle. It is a device with a combination of accelerometer, gyroscope, and digital motion control processor. MPU6050 uses the I2C protocol to communicate with the MCU hence the accelerometer in the sensor works on the piezoelectric principle. When it is tilted, a mass in the device will move in the inclination direction due to gravity. When the mass hits the wall in the device, the piezoelectric current is produced thus producing an output current that can be used to determine the inclination angle. The system uses this characteristic to control the robotic arm's movement. The MPU6050 sensor is placed on the user's elbow and is used to control the rotation and elbow joint of the robotic arm. When the user lifts or moves their elbow left or right, the robotic arm will move accordingly to the user's hand movement.

F. NRF24L01+Transceiver Module

NRF24L01+ transceiver module is a wireless module that works in the 2.4 GHz frequency band and uses Gaussian Frequency-Shift Keying (GFSK) modulation to transmit data. The module can be programmed to be a transmitter or receiver. For the two transceiver modules to communicate with each other, both devices must be on the same channel. The channel is set at a certain frequency for data transmission to take place. NRF24L01+ starts communication by sending data packets to the receiver. When the data packet is received by the receiver, it will send an acknowledgment packet back to the transmitter. Upon receiving the acknowledgment packet, the transmitter will assert interrupt signals to show that new data is available. In the case where the transmitter did not receive the acknowledgment packet, the data packet will be retransmitted by the module again and wait for an acknowledgment. This is known as automatic packet handling. In this system, the program will run in a continuous loop until the power source is off. The transceiver module will start to transmit data to the receiver once the sensors have been initialized and calibrated to the receiver. The data transmitted will then be received by the receiver and control the robot manipulator accordingly.

IV. PERFORMANCE TESTING AND SIMULATION RESULTS

The overall performance of the developed system has been evaluated by conducting various simulations and relevant tests.

A. Wireless Gesture Control Test

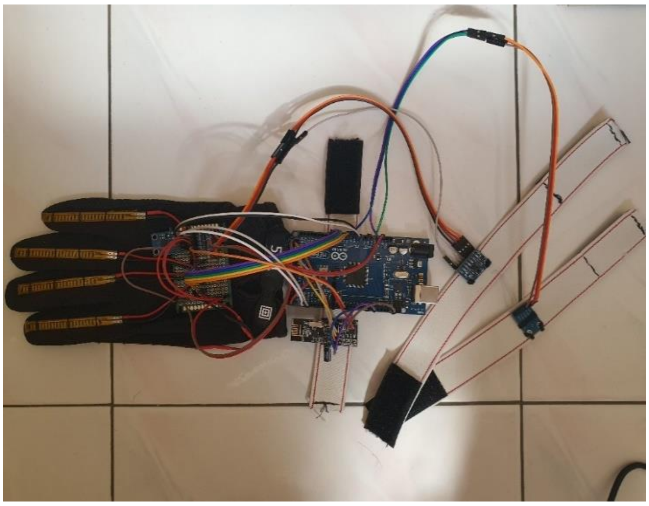

Fig 9. Wireless Gesture Controller

Fig.9 shows the hardware setup of the wireless gesture controller. The connection of the controller is based on Figure 2 and it has four wearable parts. The first part is the hand glove. It consists of five flex sensors and a prototype circuit board with an ADXL335 accelerometer and a logic level shifter. The hand glove is worn by the user on their hand and it is used to control the robotic hand and wrist joint of the robotic arm. The second part consists of an Arduino Mega and NRF24L01+ transceiver module. This part is attached to the user's forearm using an elastic band. The third and fourth parts are the MPU6050 and ADXL335 and they are attached to the user's elbow and shoulder respectively. The MPU6050 is used to control the elbow joint and base rotation while the ADXL335 controls the shoulder joint of the robotic arm.

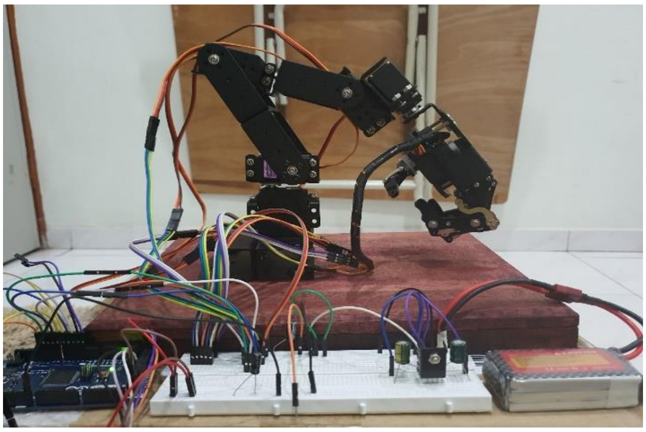

Fig 10. Robot Manipulator

Fig.10 shows the hardware setup for the robot manipulator. The connection of the hardware setup is based on Fig.6. The robotic arm has 6DOF and 5 moveable joints. They are the Base, Shoulder, Elbow, and Wrist that can roll and pitch. A robotic hand is fixed to the Wrist joint of the robotic arm as the end effector. It has five individual fingers that are controlled separately by servo motors.

Fig 11. Sample Results1

Fig 12. Sample Results 2

Fig.11 and 12 show the sample results of the proposed system. The wireless gesture controller can successfully control the robot manipulator wirelessly. The hand movements from the user are reflected directly to the robotic arm. However, there are several errors in the system. The wireless gesture controller will cease working intermittently due to the MPU6050 I2C bus error. The system has to be reset for it to be functional again. It is also found that the Base, Shoulder, and Elbow joints of the robotic arm are unable to sustain the weight of the Wrist joint and robotic hand. This causes the robotic arm to have limited movements. Although there were some errors in the system, the robotic arm is still functional.

V. Conclusion

It is developed a robotic arm to handle Nuclear wastes by moving radioactive waste without human interaction. The designed robotic arm can be controlled wirelessly through gesture control from a safe distance without exposing radiation. The system is enabled to transmit and receive the signals wirelessly. The wireless gesture controller also conveys gesture movements from a real person's arm to a robot manipulator. The prototype is contructed using a pair of NRF24LOI+ transceiver modules and tested by fixing it into the movable joints of the operator.

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