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Ideas and Solutions for Nation-building

Wireless Controlled Robotic Arm for Handling Hazardous Chemicals

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Abstract: In the present era of fast advancing technology, various robots and machines have been made to replace manpower with more efficient and safer means. Robots and machines are mostly utilized for repetitive and dangerous tasks such as handling hazardous chemicals, bomb diffusal, and factory assembly. This research paper presents the development of a wireless controlled robotic arm aimed to be used for handling hazardous chemicals. The robotic arm moves with 6 degrees of freedom (DOF). The robotic arm itself is made of 3D printed polylactic acid (PLA) material and is modeled with three primary links that are connected with digital servo motor. The controller module is in the form of a glove with flex sensors and accelerometer-gyroscope sensor attached to it. A low cost microprocessor chip (MPU) integrated with micro-electromechanical system (MEMS) is used to detect human movements in x, y, and z channel. This sensor is equipped with digital motion processor (DMP) that performs calculation with the sensor readings and reduces the load for the Arduino. Filter is applied to sensor values to reduce noise in the readings due to sudden movements. The wireless communication between the glove controller and robotic arm has been implemented using ZigBee protocol interface. The system has been developed using Arduino to control sensors, XBee module, and servo motors. The outcome is the robotic arms movement is a mirror of the human movement. Different tests such as range test, transfer test, height test, lateral test, pouring test and an overall test were conducted in order to determine the viability of the arm.

Keywords: robotic arm, degrees of freedom, inertial sensor, ZigBee, 3D printing, Arduino

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1. INTRODUCTION

One of the top technologies which improve the efficiency and effectivity of human activity is robotic machinery. This type of technology is ideal for tasks which are repetitive and dangerous for humans such as factory assembly lines and chemical waste control. Unlike humans, robotic machinery is immune to fatigue and stress and are invulnerable. Humans have been developing robotic machinery for quite some time, and now, this technology is becoming commonly known by society. Technology such as unmanned aerial vehicle and assembly robots are a few examples of robotic machinery that have become common in today's times. The common factor in these machines is that they all can be manipulated and programmed to follow certain instruction in order to perform a certain task (Baker and Ubhayakar, 1990). In this study, the main focus will be the development of a robotic arm designed for transferring hazardous chemicals controlled wirelessly by human hand movements. The gesture information, which will be the basis of the robotic arms behavior (Pititeeraphab and Sangworasil, 2015) will be collected through a glove controller equipped with flex sensors, and combination of accelerometers, and gyroscopes (Verma, 2013). Before transmitting the sensor readings, filtering of sensor values is necessary to reduce any noise in the readings caused by sudden movements. The data will be transferred via ZigBee protocol interface (Farahani, 2008), (Bhuyan and Mallick, 2014) attached to the user and arm controller. This will allow the user to control the robotic arm from a distance. This study aims to create a logical microcontroller based robotic arm that can follow the user's actions using a glove equipped with sensors. Microcontrollers have programmable input and output peripherals which makes it very important for building robots and other computer related mechanisms (Smith, 2011). The robotic arm will be operated inside a closed workplace since it handles hazardous chemicals. The user has a clear line of sight with the robotic arm. The robotic arm will have 6 degrees of freedom (DOF) and the end effector will have two fingers. The data measured by the flex sensor (Syed et al., 2012) and MPU6050 (Gyro and Accelerometer senor) (Bhuyan and Mallick, 2014) will be the basis of the robotic arms behavior and movement. The top concerns in the construction of the robotic arm will be the efficiency and response time for the robotic arm to recognize the gesture, as well as its capability to lift objects, with the maximum weight of 100g and transfer it to another point within a 2ft diameter contained workspace. The workspace is see-through measuring 2 ft. by 2 ft. area with obstacles where the robot arm will be moving around. The response time for the robotic arm must not be greater than 2s. The testing material that will be used for the implementation are non-toxic liquids with different viscosity, the use of hazardous chemicals is not necessary because the goal is to test the functionality of the robotic arm. The container used for testing will be provided.

2. METHODOLOGY

2.1 Robotic Arm Construction

The construction of the robotic arm is focused on the selection of the appropriate input sensors and output servo motors that will be able to properly control the robotic arm. The Arduino microcontroller boards are used because of its number of inputs and outputs and ease of use in prototyping (Smith, 2011), (McComb, 2010). The XBee module (Bhuyan and Mallick, 2014) is used to provide wireless connection with low power consumption in short range applications. The MPU6050 sensors are used to provide the accelerometer and gyroscope data for the controller. The robotic arm is made from 3D printed material to minimize the weight (Kim et al., 2015). The testing process for the robotic arm is divided in several parts that evaluates the individual movement of the robotic arm during operation. The final step in the testing process is the combination of all movements and evaluation of all factors that determine whether the robotic arm can handle and transfer liquids wirelessly.

2.2 Implementation

Shown in Fig. 2.2.1 is the methodological approach of the research project. It started in designing the robotic arm structure and computing for the torque of each motor in the arm. The selection of motors is made based on the computed torque for each joint of the arm. The microcontroller is chosen based on its data rate and how many I/O devices it can handle. The Xbee module is chosen based on its maximum distance and its availability in the market.

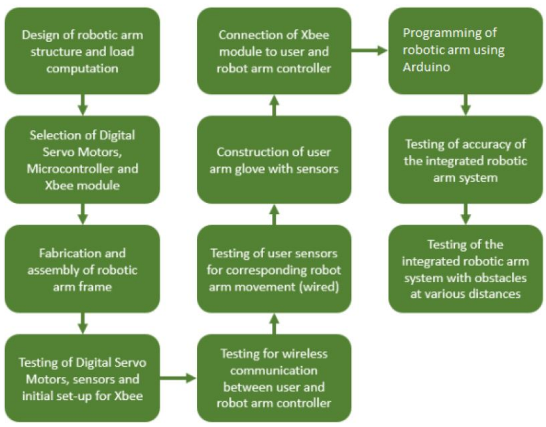

Fig. 2.2.1. Flowchart of the Methodology.

The fabrication of the arm frame is done via 3D printing wherein the material's sturdiness is considered making sure that the material can withstand the ideal forces. The robot arm is constructed by placing the servo motors to robotic arm joints and followed by the construction of user glove controller. Various input sensors are placed to glove controller and is set to specific position for corresponding human joints. The last integration of the system is the connection of Xbee modules to the user and robot arm controller specifically Arduino modules. Lastly, software is developed for the mapping of input readings from sensors to corresponding servo movements. There are some robotic arm movements that a human cannot perform. Because of that, the glove controller and robotic arm is configured to corresponding translation of input movement to specific robot arm movement. The following are the corresponding movement of user controller and robot arm:

1. Fig. 2.2.2 shows that when the glove controller is extended horizontally, the robotic arm will extend its arm horizontally up to the front end of the workspace.

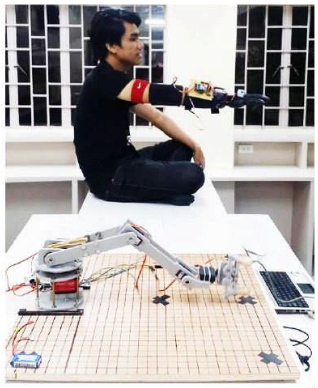

Fig. 2.2.2. Arm in raised forward position.

2. Fig. 2.2.3 shows that when the glove controller is extended upwards, the robotic arm will raise its shoulder and elbow. The wrist pitch will move its rotation to horizontal axis respectively.

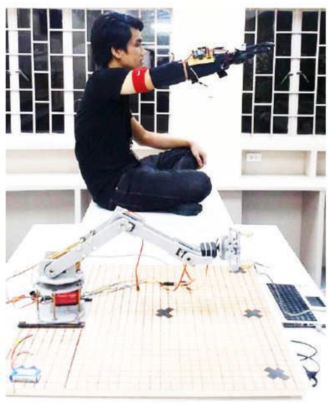

Fig. 2.2.3. Arm in raised upward position.

3. Fig. 2.2.4 shows that when the glove controller is towards the user with the forearm section

perpendicular to it, the robotic arm will raise its shoulder to about 65 degrees rotation, lowered its elbow until it becomes perpendicular to the ground. The wrist pitch will move its rotation to horizontal axis respectively.

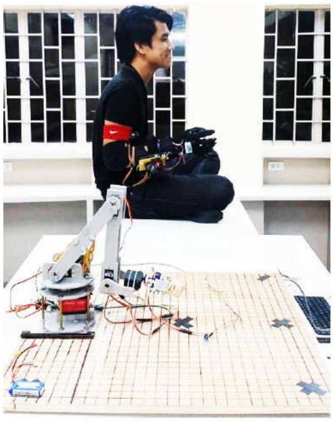

Fig. 2.2.2.4. Arm in tucked position.

2.3 Software Development

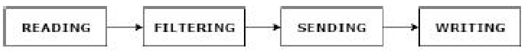

Fig. 2.3.1. System Process Flow.

The process flow of the system is shown in Fig. 2.3.1. The first process is acquisition of sensor readings from the glove controller. The first primary input device are the flex sensors. These sensors are connected in a voltage divider circuit. The output voltage reading is obtained by measuring the voltage from the second resistors that is connected in series to the flex sensor. This analog voltage is connected to the analog input port of the Arduino Mega. The analog input ports on the Arduino Mega have an analog to digital converter with 10bits of resolution. An input ranging from 0V to 5V will be translated to integer values ranging from 0 to 1023. The short flex sensor will then have an integer value of 40 when bent and 90 when straightened. The long flex sensor will have an integer value of 150 when bent and 250 when straightened. The second primary input device are the MPU6050s which are inertial movement sensors that combine a 3-axis accelerometer and a 3-axis gyroscope. The values from the accelerometer and gyroscope are combined using the 6-Axis Motion Fusion on the DMP. The DMP uses quaternions to compute for the yaw, pitch, and roll values. The yaw, pitch, and roll values are measured in radians and are converted to degrees before further processing. The second process is filtering the values acquired from the sensors. The values from the inertial sensors and flex sensors are filtered to reduce spikes in the readings due to sudden movements. The graph in Fig. 2.3.2 shows the raw value compared to the filtered value of the shoulder yaw reading. The graph shows that the sudden changes are minimized and that the final output has a smoother curve than the raw values. The filtering function starts when the individual sensor values are stored in an array. After 10 readings, the total value and the average value are computed. The current average value is combined with the previous output value and a constant filter value to produce the current output using the formula shown in Eq. 1 below where "final" is the final value computed, "ave" is the average of sensor values stored in array and "filter" is the constant filter value.

$$final = (ave * (1 - filter)) + (final * filter) \quad \text{(Eq. 1)}$$

The third process is sending the filtered values via Arduino and XBee module from the glove controller to the robotic arm controller. The XBee Series 2 modules are used to transmit and receive data between the two Arduino boards. The XBee is configured using the XCTU program to operate in transparent or AT mode.

Fig. 2.3.2.Shoulder Yaw Measurements.

The transparent mode is used for point-to-point communication between devices with static addresses. This mode allows the XBee to act as a serial channel. Each data that is written to the sender XBee module is immediately transmitted wirelessly and serially to the receiver XBee module. The Serial.write() function is used to write data to the XBee Serial interface. At the other XBee module, the Serial.read()function is used to read the data that is received. The last process is writing the mapped values to each servo motor for a corresponding movement. The values obtained from the inertial sensors and flex sensors are converted to degrees using the map() function. The map() function converts an input value to the desired output value using the defined upper and lower limits. The generic syntax used for mapping is shown below.

```
servoValue = map(sensorValue,
    sensorInputLowerLimit,
    sensorInputUpperLimit,
    servoOutputLowerLimit,
    servoOutputUpperLimit);
```

The servoValue is the output in degrees that is written to the servo motors. The sensorValue is the input which can come from the inertial sensors and the flex sensors. The sensorInputLowerLimit and sensorInputUpperLimit are constant values that define the range of the input (e.g. 40 to 90 for the short flex sensor, 150 to 250 for the long flex sensor, -90 to 90 for the MPU6050). The servoOutputLowerLimit and servoOutputUpperLimit are constant values that define the range of the output (e.g. 0 to 130 for the end effector motor, 0 to 180 for the wrist, elbow and shoulder motors).

3. RESULTS AND DISCUSSION

The construction of the robotic arm is focused on the selection of the appropriate input sensors and output servo motors that will be able to properly control the robotic arm. The Arduino microcontroller boards are used because of its number of inputs and outputs and ease of use in prototyping. The XBee module are used to provide wireless connection with low power consumption in short range applications. The MPU6050 sensors are used to provide the accelerometer and gyroscope data for the controller. The robotic arm is made from 3D printed material to minimize the weight. The testing process for the robotic arm is divided in several parts that evaluates the individual movement of the robotic arm during operation. The final step in the testing process is the combination of all movements and evaluation of all factors that determine whether the robotic arm can handle and transfer liquids wirelessly. Fig. 3.2 shows an example operation of pouring a liquid to a different container using the glove controller and robotic arm setup. During the testing process, the user controller should ideally have a clear line of sight to the robotic arm. The 2ft by 2ft workspace of the robotic arm setup, shown in Fig. 3.1, will contain different containers for liquid transfer and different obstacles. Each test will be done for multiple trials and test parameters are evaluated after each trial.

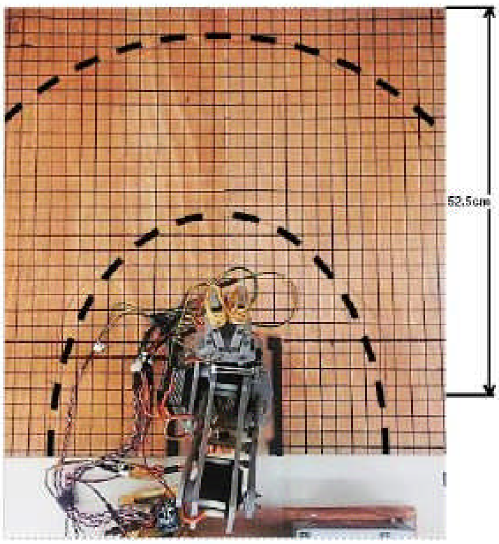

Fig. 3.1 Workspace Area

The next test is the transferring of object from point A to B without obstacle that determined the ability of the arm to successfully locate the desired location of transfer. The next test is the transferring of object from point A to B with obstacle for height movement that determined the ability of the arm to pick up objects at different elevations in the workspace. The next test is the transferring of object from point A to B with obstacle for lateral movement that determined the ability of the arm to avoid obstacle and reach short to long ranges. The next test is the pouring of chemicals to determine the ability of the arm to transfer liquids from one container to another. The last test of the system is the full operation of the arm that deals with all the specified tests above. The entire robotic arm and glove controller system was tested 10 times for manual test and 25 times of transferring tests. It was able to pass all the testing methods with at least 90% of success rate in each test. The maximum weight it can lift is 100 grams.

Fig. 3.2 Overall Operation of Glove Controller and Robotic Arm Setup

4. CONCLUSIONS

For the research to have a clear vision for its goal, it is stated from the start that there is a need in programming a machine that could operate from a distance. In the real world humans are more susceptible in accidents that happens in manufacturing factories that lacks superior machines. Humans are also most likely to make mistakes when performing tasks and when that happens it usually ends unpleasantly because it may result into injury and worst, taking a life. In order to make better machines it is considerable to develop a control that can effectively operate a machine. In this research, the machine is a robotic arm and to control it, sensors are used that are attached to the gloves. For a robotic arm to be controlled in a more efficient way, gestures can be used to give commands to the machine. The robotic arm imitates the gesture movement to perform a certain task. Movements are recognized by the sensors attached to the gloves. Sensors like the flex sensors are attached to the index finger and to the elbow because these parts of the arm only move in a single axis. The accelerometer and gyroscope sensors are attached to the wrist and to the side of the upper arm of the user to replicate its x, y, and z movement by the robotic wrist and the robotic arm. To operate at a distance an XBee module can establish connection from the robotic arm to the glove controller. This way the user of the robotic arm is much safer in transferring hazardous chemicals and other materials that are harmful to human health because of the fact that the arm can be operated from a distance. As long as the user has a clear view from the arm, it must be possible to operate it effectively. The risk for dealing dangerous materials is going to be decreased as long as the control of the arm is maintained to be accurate. In this research project, a wireless controlled robotic arm was constructed for handling hazardous chemicals. Six degrees of freedom (shoulder yaw, shoulder pitch, elbow pitch, wrist pitch, wrist roll and end effector grip) was integrated using servo motors. Two Arduino boards were utilized to recognize the user arm movements and to control the robotic arm. A complete wireless connection between the user controller and robotic arm module was established. A user glove was constructed that is equipped with multiple sensors that served as the robotic arm controller. The robotic arm was fabricated using 3D printed PLA. Based on the results, a complete connection was established between an effective distance of 10ft to a maximum of 20ft. A new way of controlling the robotic arm was implemented in this research study. A robotic arm with six degrees of freedom was controlled through various sensors. The servo mapping was able to generate the correct mapped servo values coming from the sensor readings and output it to robotic arms joints. This mapping process was able to translate the orientation of shoulder pitch, shoulder yaw, elbow, wrist pitch, wrist yaw, and gripper of the user. The range test was able to establish a good connection that varies within a range of -10dBm. The conversion of the robot arm controller was accurate since it was able meet the maximum distance error of 2cm for every transferring operation. It was able to avoid any obstacle present in the workspace, and was able to perform the pouring of chemical accurately. Overall, the robotic arm was able to perform the user movement and obtained a success rate of at least 90% in each test.

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