A Seven Degree of Freedom Lifelike Robotic Arm

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***Abstract* - Due to the increasing use of robots in industry applications, our senior design project is to modify a previous lifelike robotic arm prototype. Modifications to the current prototype include adding three new degrees of freedom, a pressure sensitive gripper, and improvement to the overall stability of the arm. The three new degrees of freedom include the roll of the upper arm, and the roll and pitch of the wrist. A pressure sensitive gripper is also incorporated into the new prototype. The gripper has two fingers for picking up items, and a pressure sensor attached to each of the gripper fingers, to allow the arm to distinguish between grasping a plastic versus ceramic cup. Through use of stabilizer linkages added to the arm joints and extra supports added to the arm base, shake and vibration of the arm is reduced. The new design addresses all necessary specifications and from the design a second generation prototype is being developed. The building of the prototype includes fabrication, programming, and testing. Upon completion, the new prototype will include seven degrees of freedom, and will be able to pick up a plastic and a ceramic cup.**

Index Terms – lifelike, robotic arm, seven degrees of freedom

INTRODUCTION

Incorporation of robots in industry is not a new concept, and advancements in robot design and their application have continued to evolve. With new knowledge and continued research suggesting health risks and hazards to humans in certain industries, including the nuclear industry, manufacturing, and space exploration, the use of robots has become more important. Telerobotics is especially innovative in that it allows an individual to control the movement of a robot from a safe location. This allows the user to avoid hazardous working conditions while accomplishing required tasks.

With the increasing use of robots in industry applications, this senior design project involves improving upon a previously designed teleoperated robotic arm. The previous robotic arm prototype, shown in Figure 1, was developed by a previous group of Central Michigan University engineering students [1]. The design included five functional joints, with one degree of freedom (DOF) each. The five DOF included two joints at the shoulder, which allowed for the adduction/abduction and flexion/extension movements of the shoulder [2]. The other three joints include a joint at the elbow which allowed for the flexion/extension of the elbow, and a wrist joint which incorporated the roll and pitch of the wrist. Of the five joints, the elbow and shoulder were the only two which were wirelessly programmed. The design included gears and a motor attached to the bicep of the robotic arm. These should have allowed for the adduction/abduction movements of the arm, but were not programmed into the sensory system.

The sensory system of the robot was made up a MAVRIC-IIB wireless receiver and Arduino hardware and software. The MAVRIC-IIB was a microprocessor used to control the arm's servomotors. The Arduino was the wireless controller that used Wi-Fi to communicate between the position sensors (used to control the motion of the arm) and the MAVRIC-IIB.

Originally, the robotic arm was intended to be used as a prosthetic, but due to limitations the project focus was shifted to a teleoperated robotic arm. In improving upon the previous design the focus of the project has again shifted. The new robotic arm design is a seven degree of freedom lifelike robotic arm, which uses programmed operations to control the movement of the arm. The robotic arm was changed from a teleoperated robotic arm to one which uses programmed operations due to limitations with the position sensors used to control the motion of the arm.

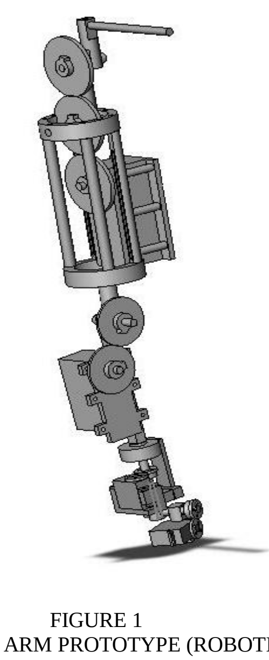

FIGURE 1
ORIGINAL ROBOTIC ARM PROTOTYPE (ROBOTIC ARM 1.0)

In addition to moving from a teleoperated robotic arm to one which uses programmed operations, design improvements have also been made to the shoulder, elbow, and wrist. The new design has seven DOF, including the addition of the roll of the shoulder, a new wrist mechanism, which replaces the previous wrist design, and the addition of an end-effector. The new wrist design still incorporates the roll and pitch motions of the wrist included in the previous design. The end-effector is pressure sensitive for the goal of picking up a plastic cup without crushing it and a ceramic cup without dropping it. The previous design experienced a great deal of shake and vibration when the arm moved from one position to another; the new design incorporates mechanical linkages at the joints and additional support for the arm base in order to reduce the shake and vibration by fifty percent. A description of the design, including improvements and design selection, is discussed in detail in the following sections, along with fabrication, programming, testing, and final results.

DESIGN DESCRIPTION

In improving the previous robotic arm prototype new components were incorporated into the design, and changes were also made to in the layout of parts from the previous design. Changes include adding four new degrees of freedom, the roll of the upper arm, the roll and pitch of the wrist, and the addition of an end-effector. The following is a detailed description of the new design of the robotic arm prototype.

The shoulder design for Robotic Arm 2.0 includes a gear reduction from three to two gears. The gear ratio can be reduced because all three gears have the same diameter; therefore there is no change in torque between the gears. The servomotor originally placed on the bicep of the arm was moved to the clavicle in the new design. Moving the servomotor to the clavicle helps reduce the bending moment at the shoulder joint and at the end of the shoulder shaft. The bending moment is not entirely eliminated due to the addition of a new, smaller servomotor on the bicep, as well as the addition of an end effector. Figure 2 shows a comparison between the shoulder design used for the original prototype and the new shoulder design.

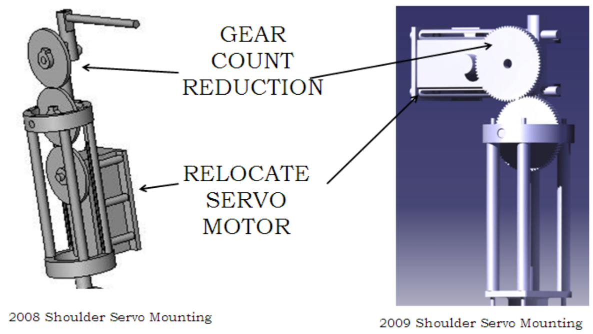

FIGURE 2
SHOULDER DESIGN COMPARISON

The bicep design is similar to the design used for Robotic Arm 1.0. The main difference is the large servomotor on the bicep is replaced with a smaller servomotor, which is used to control a gyro located at the elbow. The new servomotor has a torque of 765 oz/in, and it does not experience the resultant forces from the forearm because it is fixed to the top plate of the gyro. The cage from the original bicep design is kept in the new design to house the new servomotor.

As previously stated, a gyro is used at the elbow joint. The gyro adds the degree of freedom that allows the roll of the upper arm. The gyro is made out of aluminum and helps to minimize the increased bending moment and shear stresses at the shoulder. Figures 3 and 4 depict the gyro which is being used at the elbow.

The forearm design is similar to the previous forearm design. It is made out of aluminum. The only addition to the forearm is stabilizer linkages. Stabilizer linkages are added to the forearm to help reduce the amount of shake and vibration the previous design experienced when moving from one position to another.

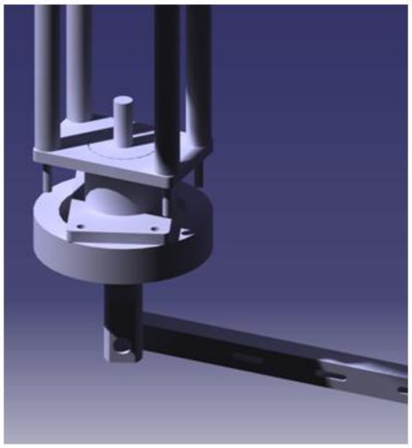

FIGURE 3
GYRO AT ELBOW JOINT

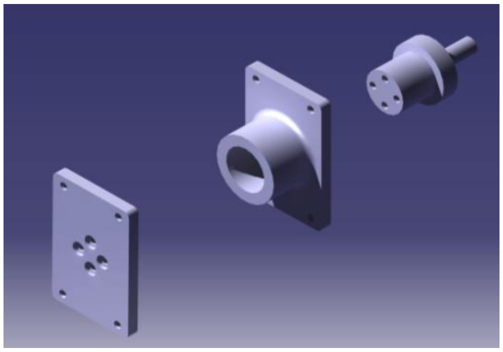

FIGURE 4
EXPLODED VIEW OF GYRO DESIGN

A new wrist is incorporated into the prototype design. In order to attach the wrist to the forearm a wrist mount with an interference fit is used. An exploded view of the wrist mount is shown in Figure 5. As shown in the figure there is a recess cut out of the wrist mount. This recess houses the servomotor for the wrist and it also reduces weight. The wrist itself was purchased from Servocity. It is a pan and tilt system, which is intended for use with a camera but is ideal for the wrist design because it allows for the required roll and pitch motions. The pan and tilt system requires two servomotors and is made out of plastic. Figure 6 shows the pan and tilt system used for the wrist design [3].

The gripper was made out of Deriln© machinable plastic, with the exception of the angle iron and pins. The machining of the gear linkages and gripper fingers were machined in house using a band saw. The mounting base of the gripper is made out of 12 gauge steel. Plastic reduction gears and a 90-degree servomotor were purchased from Servocity. The reduction of the gripper gears allow the gripper fingers to open to 45-degrees. Two parallelogram linkages are attached to each of the two gripper fingers, keeping the fingers parallel to one another. A detailed drawing of the gripper is shown in Figure 7.

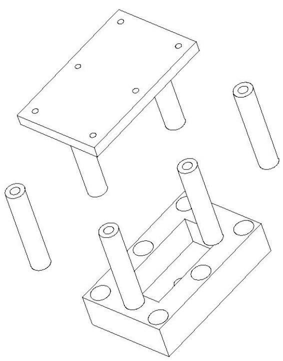

FIGURE 5
EXPLODED VIEW OF WRIST MOUNT

FIGURE 6
PAN AND TILT SYSTEM USED FOR WRIST DESIGN

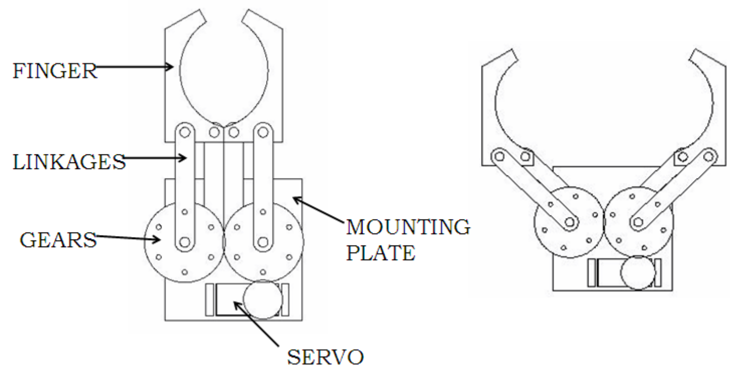

FIGURE 7
GRIPPER DESIGN

Pressure sensors are attached to each of the gripper fingers. The two pressure sensors, a 0.2 inch force sensing resistor kit, and a phidget interface kit 8/8/8 were purchased from Trossen Robotics for use with the gripper [4]. The pressure sensors are used to help control the force applied to the object being lifted. The gripper is required to lift both a plastic cup without crushing it, and a ceramic cup without dropping, which is achieved through use of the pressure sensors.

As previously described, the design for the new robotic arm prototype includes many improvements and additions to the original prototype. These improvements include moving the servomotor previously located on the bicep to the clavicle and a gear reduction at the shoulder. A gyro at the elbow allows for the roll of the upper arm, and additional DOF are added through the roll and pitch of the wrist. The addition of an end-effector adds another degree of freedom, allowing the arm to perform the task of picking up various objects. A drawing including all the parts of the new design, minus the wrist, is shown in Figure 8.

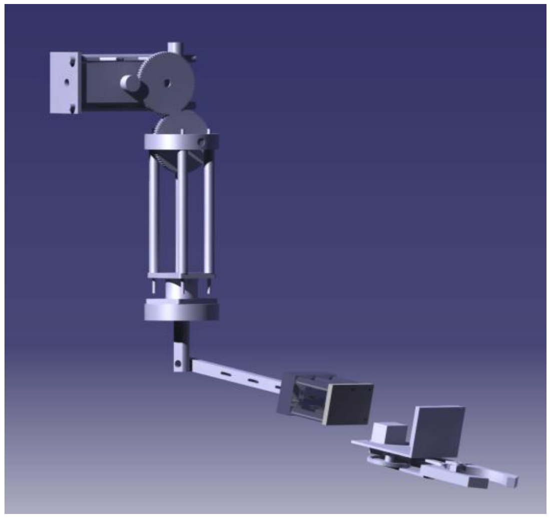

FIGURE 8
FULL ARM ASSEMBLY

MANUFACTURING CONSIDERATIONS

Most of the design of the new prototype is made out of aluminum, including the shoulder mount, gyro, forearm, and wrist mount. Due to lack of experience and necessary machinery at the university, the machining of the aluminum and steel parts of the design has been outsourced. Hytrol Manufacturing, in Garden City, MI, has agreed to provide the required machining at no cost [5]. This allows for a reduced cost of the project, and additional time which would have been spent on machining has been used to produce the gripper and to work on programming.

The other necessary parts have been purchased from various suppliers. The pan and tilt system used for the wrist, all required servomotors, and the gripper gears, along with other miscellaneous materials were purchased from Servocity. The force sensing resistor (FSR) kit and phidget interface board, which allow the gripper to be pressure sensitive, were purchased from Trossen Robotics. The Derlin© machinable plastic used for the gripper fingers and linkages was purchased from Interstate Plastics [6]. The total cost for the project is estimated at $546.

PROGRAMMING REQUIREMENTS

Programming is ongoing. The team has begun looking at the program code and wiring used in the original model. A fellow electrical engineering student has offered to provide some assistance with the necessary programming.

The required programming includes finding or developing code which allows the arm to perform programmed operations. The programmed operations are used to demonstrate that all seven DOF are operational. It also allows for the arm to be program to move to a specified location where it is then programmed to pick up either a plastic or ceramic cup, and then the arm is moved to another location where it safely releases the cup.

Programming is also required in order to run the servomotors which control the various arm motions. The team, with assistance from fellow electrical engineering students, has developed code for running the servomotors. The servomotors are connected to a breadboard and run off the arduino duemilanove. The pressure sensors also require programming in order to function. The team has also developed code to run the pressure sensors off the arduino duemilanove.

By combining the code for the pressure sensors and servomotors the team is able to control the increments and speed of the servomotors, which control the movement of the gripper fingers and the arm. Currently the code is written so that when the pressure sensor feels a pressure less than 200 (the arduino gives off a reading between 0-1023) the servomotor, which moves the gripper fingers, moves in 50 degree increments. Once the pressure exceeds 200 the servomotor is then programmed to change from 50 degree increments to 15 degree increments. Once the pressure reaches 700 the servomotor controlling the gripper fingers is programmed to turn off, and the servomotor programmed to control the forearm is turned on. This ensures that the arm does not move or try to lift the object before it has grasped it. The experimental set-up of one of the pressure sensors and the two servomotors used to control the gripper fingers and forearm is shown in Figure 9. The exact pressure values necessary to grasp a plastic and ceramic cup will need to be determined once the arm is fully assembled and the team is able to test the sensors with them attached to the gripper fingers.

Although the team has limited experience with programming there is a clear list of the programming required to complete the project. Through the use of resources at the university and online, the team plans to continue researching program code and enlisting the help of others to complete the required programming.

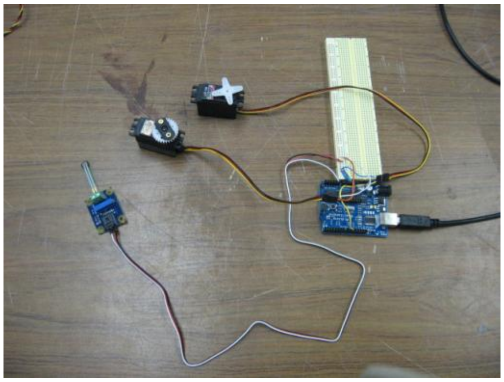

FIGURE 9
EXPERIMENTAL SET-UP USING PRESSURE SENSOR AND SERVOMOTORS

BENCHMARKING AND PROTOTYPE TESTING

Currently the project is in the construction phase; therefore no testing has been done on the new prototype. Although testing has not been done on the new prototype, the previous prototype was used as a benchmark to assist in incorporating improvements into the new design. Benchmark testing was done to determine the amount of slop in the joints of the previous prototype.

The previous design experienced a large amount of shake and vibration when moving from one position to another. In order to reduce the shake and vibration in the new design static testing of the joints was done. The testing not only showed the amount of slack in the joints tested, but it also indicated the shake the arm experienced was a result of loose connections in the robot frame. This is important to note because it had been expected that the shake resulted from backlash in the gears, but this was not the case. Table I displays the results obtained from the testing.

TABLE I
BENCHMARK TEST RESULTS

Joint	Slack (in)	Std. Dev
Elbow	1.250	0.530
Shoulder	1.656	0.221
Elbow Out	0.156	0.044
Shoulder Out	1.219	0.575
2x4 base	0.500	0.354

Additional testing of the new prototype will include making sure the programming code and wiring of the servomotors and pressure sensors is proper implemented. The DOF of the joints will also be tested to ensure they are operating correctly. The benchmark testing may need to be repeated using the new prototype to ensure the shake and vibration of the arm was reduced by the requirement of fifty percent.

FINAL RESULTS

The design phase of the project is complete and the building of the prototype is underway. The chosen design, after being compared with other designs, was determined to be the best option for meeting all project requirements. Upon completion of the project the prototype will be a functioning seven DOF lifelike robotic arm. It will include a pressure sensitive gripper capable of distinguishing between the force needed to pick up a plastic cup and a ceramic cup. The shake and vibration of the robotic arm will have been reduced by fifty percent from the original design, therefore improving the stability of the arm. The robotic arm will operate using programmed operations, allowing the arm to move and perform specified tasks. The final prototype will meet all necessary specifications and will be an improvement on the original robotic arm prototype.

CONCLUSION

As the application of robots continues to grow it is important to acknowledge the benefits robots can provide. Robots are used in industry to perform tasks, which would be hazardous to a human, and have also been used to aid doctors in surgery. The use of teleoperated robots provides even more opportunities. Teleoperated robots allow an individual to control a robot from a safe location, while the robot mimics the motion of the controller. For these reasons, this senior design project included the design and implementation of a seven DOF lifelike robotic arm.

The lifelike design of the robotic arm allows the user to more easily interpret the movement of the robot. Although the arm is no longer teleoperated, it is possible for a future group of students to improve upon the limitations with the original design's wireless controllers and once again make the arm teleoperated.

At this time the design phase of the project is complete. The next step of the project process is assembly of the prototype. Hytrol Manufacturing has finished machining the aluminum and steel parts of the design, and as a result assembly of the arm has begun. Figure 10 shows the current assembly of the arm. The team started assembling the arm starting at the shoulder and is working down the arm. The team has all necessary parts to finish assembling the arm, and necessary modifications and adjustments have been made to the parts to insure that they fit together. The pan and tilt system used for the wrist has already been assembled and was tested in order to verify it was working properly. The gripper fingers and linkages have been machined out of plastic.

This senior design project has been both challenging and exciting, and upon completion the team will have designed and constructed a seven DOF lifelike robotic arm. The design will incorporate the addition of the roll of the upper arm, a new wrist design incorporating the roll and pitch of the wrist, and an end effector. The gripper will be pressure sensitive; it will be able to pick up a plastic cup without crushing it and a ceramic cup without dropping it. The design also improves the stability of the arm through use of stabilizer linkages and extra supports at the arm base. The new design addresses all necessary specifications and will be used to develop a second generation prototype.

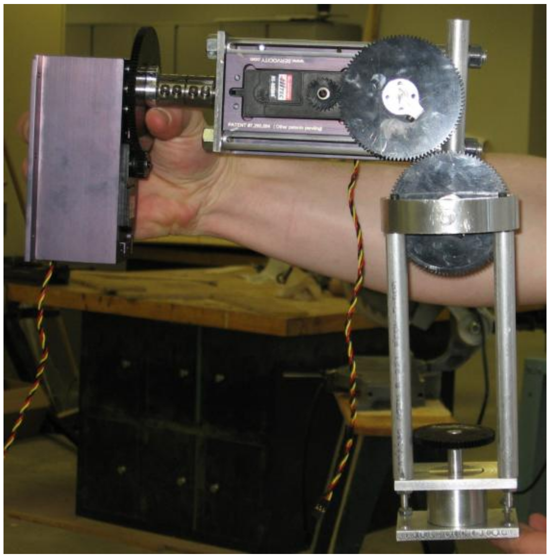

FIGURE 10
CURRENT ARM ASEMBLY INCLUDING SHOULDER AND GYRO AT ELBOW JOINT

ACKNOWLEDGMENT

A special thanks to the following companies and individuals for assisting the team in the design and construction of the robotic arm prototype.

- Hytrol Manufacturing
- JW Machining

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