Robot Manipulator for HERO

by

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Submitted to the
MECHANICAL ENGINEERING TECHNOLOGY DEPARTMENT
In Partial Fulfillment of the
Requirements for the
Degree of
Bachelor of Science
in
MECHANICAL ENGINEERING TECHNOLOGY
at the
OMI College of Applied Science
University of Cincinnati
May 2008

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ABSTRACT

First Response Robotics has a need for a robotic manipulator for its Hazardous Environment Robotic Observer (HERO). HERO is limited on the functions it can perform because of not being able to interact with its environment. With a robot manipulator HERO will be able to unlash doors and transport objects weighing up to five pounds to a safe location, while being controlled remotely using live video feed so operators can visually see the environment around the robot. The design of the robot manipulator is broken into the arm and gripper; the controls system of the project will be outsourced to Robotex in California. This report is to validate the design of the gripper. The key features the gripper must have are the ability to open five inches, unlash a door that is unlocked, the unit must be light weight, and be removable from the arm. The scope of the project is to eliminate the current limitations HERO faces when in use. This report includes the research, design ideas, and the manufacturing process for the gripper.
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BACKGROUND
The Hazardous Environment Robotic Observer (HERO), shown in Figure 1, is made by First Response Robotics (FRR) and is used in both Hazardous Materials (HAZMAT) and Tactical situations. The Environmental Protection Agency (EPA) uses HERO for HAZMAT situations that might require carrying measurement equipment into a contaminated area. Various state and federal departments use HERO as an observation robot, to be used in case of a bomb threat or any other dangerous situation. The main role that HERO serves is it takes the place of a person in a dangerous situation, thus saving lives. In each of these situations HERO’s role is limited to only observation, meaning the robot cannot effectively interact with its environment. Its observation is also limited to halls, rooms with open doors, and main access corridors. The scope of this project was to eliminate these limitations so that HERO could be used more effectively.

Figure 1-Current HERO Robot

FRR would like to have a robotic manipulator for HERO. This manipulator would enable HERO to pick up objects in contaminated areas, and also grant it access to rooms that have closed doors. Also the robot manipulator would allow FRR to compete with other companies who have already incorporated an arm on their observer robots.
RESEARCH
The design of the robot manipulator will not only meet the specifications given by FRR, but will incorporate other desirable features that were found when researching existing robotic observers that are equipped with robot manipulators. Professionals in the robotic field, along with potential customers were surveyed to find out the importance of these various features.

EXISTING PRODUCTS
FRR’s biggest competitor is iRobot who produces the PackBot. Figure 2 shows the PackBot 510 with First Responder Kit. “In addition to providing situational awareness through real-time video, audio and sensor readings, the PackBot 510 with First Responder Kit adapts to a wide variety of scenarios, including the investigation and disposal of explosive materials, hostage situations, search and rescue missions and other dangerous incidents.” (1) Another competitor is Oceaneering with its Terabot shown in Figure 3-Terabot is designed to operate in harsh environments. It’s “static and dynamic seals make it water and dust resistant, and capable of withstanding intense rain, heavy dust, and short periods of full immersion.” (2) Although the Terabot has the ability to pick up objects, it cannot open doors with its current gripper.

Figure 2-PackBot with First Responder Kit

Figure 3-Terabot
An example of an existing product on the market is the Doorknob Turner shown in Figure 4. “Portable turner slips over the doorknob. Hand slides in the other end for a quick and easy way to open a door.” (3) The problem with this device is even though it can be used as a gripper to open a door, it is unable to pick anything up.

**CUSTOMER RESEARCH**

Thirteen professionals in robotics along with potential customers responded to a survey in which they were asked to rate the importance of the features the arm and gripper were to have. The results are located in (Appendix B). The results in order of importance are

- Ability to replace gripper with another tool (4.1)
- Ability to hold torque in case of power loss (4.0)
- All materials weather resistant (3.5)
- Ability to assemble and disassemble links with ease (3.3)
- Compact design in stowed position (3.1)

The QFD diagram found in (Appendix C) takes the survey results and incorporates the sales points of each of these features, which gives the relative weight for each feature. The last four features changed their order of importance because of the sales points. The features with their relative weight are

- Ability to replace gripper with another tool (.21)
- Ability to hold torque in case of power loss (.18)
- Compact design in stowed position (.16)
- Ability to assemble and disassemble links with ease (.15)
- All materials weather resistant (.15)

The reason there are no features for the gripper is because originally the project was split between two designers: one responsible for the mechanical components and the other responsible for the controls. During the design phase of the project the controls portion became too complex for MET
students. FRR then outsourced the controls portion to a company in California. Originally the gripper was going to be purchased, but FRR stated it would like one designed. Instead of the project being divided into controls system and mechanical system, it became divided into the arm and the gripper. This change happened after it was feasible to complete new customer surveys for the gripper, so FRR stated the features that the gripper must have and the features that the company would like to see incorporated. These features are what drove the design of the gripper, and they can be found in the design section of this report.

**PRODUCT OBJECTIVES**

FRR has stated that the robot manipulator must have the following characteristics:

- Weight of less than 15 pounds
- Ability to pick up 5 pounds
- Ability to unlatch an unlocked door

These functions along with the features listed in Customer Research were designed into the robot manipulator. Table 1 shows a complete list of functions that the robot manipulator will have and how these functions were to be measured to ensure that they were incorporated into the design.

<table>
<thead>
<tr>
<th>Function</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light weight no more than 15 pounds</td>
<td>Measured</td>
</tr>
<tr>
<td>Ability to pick up 5 pounds</td>
<td>Observed</td>
</tr>
<tr>
<td>Ability to unlatch an unlocked door</td>
<td>Observed</td>
</tr>
<tr>
<td>Ability to replace gripper with another tool</td>
<td>Removable gripper</td>
</tr>
<tr>
<td>Ability to hold torque in case of power loss</td>
<td>Observed</td>
</tr>
<tr>
<td>Compact design in stowed position</td>
<td>Fits in a box 10” x 10” x 26” in stowed position</td>
</tr>
<tr>
<td>Ability to assemble and disassemble links with ease</td>
<td>Will require common tools to do maintenance</td>
</tr>
<tr>
<td>All materials weather resistant</td>
<td>List of materials</td>
</tr>
</tbody>
</table>

**PROOF OF DESIGN**

The Proof of Design can be found in Appendix F. It shows how the features listed above were designed into the arm. The two features that affect the gripper are the ability to replace the gripper with another tool and all materials weather resistant. The ability to replace the gripper with another tool was designed into the gripper by having an adapter plate mounted to the bottom of it, so that the
user can just unbolt the adapter plate to change the end-of-arm-tooling. The second feature was
designed into the gripper, by having the motor enclosed, and all fasteners made of stainless steel.

**DESIGN**
First Response Robotics has stated that the gripper must be able to pick up five pounds and open
a door knob. These are some of the features the company would like to see incorporated into the arm:
ease of maintenance, ability to replace fingers with another object with ease, light weight, ability of
the fingers to open five inches, and a small overall size.

**ALTERNATIVE DESIGN**
Three different design concepts were made for FRR to choose from. The three design ideas
were a parallel gripper, an angular gripper, and a variation of the first angular gripper. These
concepts can be found below in Figures 5-7. Along with the design concepts, a weighted decision
matrix was given to FRR to help in the decision making process.

Table 4 shows the alternative design weighted decision matrix which was used to select the best
design for the gripper.
Design 3 a variation of the angular gripper in Design 2 was the best concept all around and was the concept that FRR selected. The main advantage of Design Concept 3 was the placement of the fingers outside of the gearbox. With the fingers outside the gear box they can be easily removed to place different fingers on if a situation calls for them.

**Material Selection**

Material selection is an important step in the design process, and many factors have to be considered when selecting a material. In both the arm design and the gripper design the following criteria were used for material selection:

- Weight
- Stiffness
- Strength-to-Weight Ratio
- Ductility
- Cost

The Ashby chart found in Appendix I was used in narrowing down the selection to the following:

- Steel
- Aluminum
- Composites
- Titanium

These materials were then used in a weighted decision matrix to determine the best material for the project. The decision matrix can be found in Appendix J. The best material for the project using
the selection criteria previously mentioned was Carbon Fibers. Carbon Fibers were not used because they cannot be machined or welded very easily. The material selected for the project was Aluminum 6061-T6 which scored second highest and has the advantage of being able to be welded and machined.

**DESIGN CALCULATIONS**

When designing the gripper one of the main features was for the gripper to be able to open a door. In order to do this the force which was needed to be applied to the door knob to keep the fingers from slipping had to be found. Builders Hardware Manufacturers Association (BHMA) states that the torque needed to open a door handle will not exceed 20 in lb. From Equation 1 the force needed to be applied at the door knob was found. Figure 8 shows where these forces are applied.

Equation 1-Force

\[ F = \frac{T}{r} = \frac{20 \text{ in} \cdot \text{lbs}}{1 \text{ in}} = 20 \text{lbs} \]

![Figure 8-Forces at Door Knob](image)

Since the fingers are going to be coated in rubber to improve their ability to grip objects this force will decrease. Equation 2 shows the calculations to find the normal force, which is the force the fingers need to apply to keep the door knob from slipping. According to the Engineers Handbook the coefficient of friction between rubber and solids range from 1-4. (4) This is due to the fact that rubber is synthetic and can be made to have different properties. For our purposes we used 2, because it is in the lower end of the spectrum. Figure 9 shows a diagram of these forces. Since two fingers are being used the force was divided by 2 giving us a total force of 5 lbs per finger.

Equation 2-Normal Force

\[ N = \frac{F}{\mu} = \frac{20 \text{ lbs}}{2} = 10 \text{ lbs} \]

![Figure 9-Normal Force](image)

Sizing the motor was done using the 5 lb normal force. Figure 10 shows the gear schematic which was used to calculate the torque that is needed to be produced by the motor. Equation 3 shows
how this torque was calculated. Since the motor is powering both fingers the 12.5 in*lbs was doubled causing the total motor requirements to be 25in*lbs.

Equation 3-Motor Calculations
\[ T = F \times r = 5\text{lbs} \times 2.5\text{ in} = 12.5\text{ in}^*\text{lbs} \]

The motor selected was a Hitec HSR-5990 Titanium Gear Robot Servo. The motor is rated for 26 in*lbs. Since the motor provides enough torque, the same gears were used for the entire gripper. There is no need to increase torque or reduce speed since the torque is already reached and the controller will control the speed of the gripper. This will enable the customer to only have to keep one type of gear in stock for replacement parts.

**Finger Design**

The finger design is based on the most common type of door knob which is a 2 inch diameter ball attached to a 1 inch diameter shaft. Figure 11 shows the finger schematic. This design will enable the gripper to wrap around the door knob enabling more contact area. For opening doors that have door handles we can use the flats located at the top of the gripper to grip the handle.

**Design Analysis**

The 3-D modeling was done in Solid Works. Once the modeling was finished the model was put through Cosmos Express Package that comes with Solid Works. This software enables the user to restrain the part/parts and apply loads, along with many other features. The full assembly was tested for Von Mises and factor of safety. In Appendix J the results of these tests can be found. The overall factor of safety for the assembly was 4.5. The use of Cosmos enables the designer to speed up the process to ensure that the design will work with the given loads.

**Bill of Material**

The following table lists all the parts that are needed to make up the gripper.
FABRICATION AND ASSEMBLY

Once the design phase was finished, detailed solid work drawings were given to FRR, so that fabrication could begin. These detailed drawings can be found in Appendix K. All of the fabrication for the gripper was done by FRR. FRR’s machinist took the drawings furnished to them and imported them into Surfcam. Surfcam is a software package that enables the machine operators to take the part drawings and convert them into a program for CNC and wire EDM machines. Figure 12 shows the CNC machine that was used in fabricating the gripper. All of the gripper’s parts except the fingers were made on FRR’s CNC machine by the methods previously mentioned. The fingers were not made on the CNC machines because of their

Table 3 - Bill of Materials

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Material</th>
<th>Qty</th>
<th>Manufacture</th>
<th>Mfr. Part #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servo Motor</td>
<td>Electric</td>
<td>1</td>
<td>Hitec</td>
<td>HSR-5990</td>
</tr>
<tr>
<td>Horn</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gear</td>
<td>Annodized Aluminum</td>
<td>4</td>
<td>2024</td>
<td></td>
</tr>
<tr>
<td>Set Screw (Gear)</td>
<td>Stainless Steel</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flange Bushing</td>
<td>MDS-Filled Nylon 6/6</td>
<td>2</td>
<td></td>
<td>8975K463</td>
</tr>
<tr>
<td>Flange Bushing</td>
<td>Cut MDS-Filled Nylon 6/6</td>
<td>4</td>
<td></td>
<td>6750K131</td>
</tr>
<tr>
<td>Set Screw (Fingers)</td>
<td>Stainless Steel</td>
<td>2</td>
<td>McMaster-Carr</td>
<td>92015A110</td>
</tr>
<tr>
<td>Adapter Plate (Gripper)</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>8975K458</td>
</tr>
<tr>
<td>Driving Shaft</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>6750K191</td>
</tr>
<tr>
<td>Finger</td>
<td>Aluminum 6061</td>
<td>2</td>
<td>McMaster-Carr</td>
<td>8975K492</td>
</tr>
<tr>
<td>Flat Hex Screw (M4X8)</td>
<td>Stainless Steel</td>
<td>8</td>
<td>McMaster-Carr</td>
<td>92125A188</td>
</tr>
<tr>
<td>Gear Box</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>8975K771</td>
</tr>
<tr>
<td>Gear Shaft for Hub</td>
<td>Aluminum 6061</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idler Shaft</td>
<td>Aluminum 6061</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hex Screw (M3X5)</td>
<td>Stainless Steel</td>
<td>7</td>
<td>McMaster-Carr</td>
<td>91292A110</td>
</tr>
<tr>
<td>Hex Screw (M4X10)</td>
<td>Stainless Steel</td>
<td>4</td>
<td>McMaster-Carr</td>
<td>91292A116</td>
</tr>
<tr>
<td>Hex Screw (M4X14)</td>
<td>Stainless Steel</td>
<td>2</td>
<td>McMaster-Carr</td>
<td>91292A038</td>
</tr>
<tr>
<td>Gearbox Front Plate</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>9041K11</td>
</tr>
<tr>
<td>Motor Box</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>8975K315</td>
</tr>
<tr>
<td>Motor Box Plate</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>8975K34</td>
</tr>
<tr>
<td>Motor Mount</td>
<td>Aluminum 6061</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor Mount Cut</td>
<td>Aluminum 6061</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>Aluminum 6061</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>8975K123</td>
</tr>
<tr>
<td>6294K203</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
nonstandard shape. The shape of the fingers is critical to maintain surface contact with the door knob when opening the door. This is the reason FRR fabricated the fingers on their wire Electrical Discharge Machine (EDM). Wire EDM uses a thin metal wire to push electrons out of the way, which enables it to cut through the part without touching it. It is mainly used for parts that have critical dimensions that have tight radiuses and for parts with irregular shapes. Figure 13 shows the wire EDM that was used in the fabrication of the fingers. The entire gripper was assembled using Allen wrenches. The screws used in the assembly were set screws, 3mm hex head screws and 4 mm hex head screws. These screws range in height depending on the part they are fastening. The detailed assembly drawings can be found in Appendix L.

TESTING
The product objectives section lists the features that were incorporated into the design of the robot manipulator, and how those features will be tested. The ability to unlatch an unlocked door was tested by opening a standard office door. The door used in the test was an office door located at FRR. The door was a standard door with door knob. The ability to pick up five pounds was tested by picking up a five pound workout weight. The ability to replace the gripper was tested by unbolting the gripper from the arm and disconnecting it from the controller. These tests were conducted at FRR and a video was made to show the faculty that the features work. The feature of having all materials weather resistant was proven by a bill of materials. All of the fasteners were made of stainless steel. The other features in the product objectives deal only with the arm design. The gripper passed all of these tests showing that the features that were planned for the gripper were actually incorporated into the design.
TEAM RESPONSIBILITIES

The design team for this project was Sergey Zhemchuzhny and Jeremy Nugent. Sergey Zhemchuzhny was responsible for the design of the robot manipulator. Jeremy Nugent was responsible for the design of the gripper for the robot manipulator. The scope of this report deals with the gripper system of the robot manipulator. Table 2 shows the major deadlines for the mechanical systems of the manipulator, the full schedule with all deadlines can be found in (Appendix D).

Table 4-Major Deadlines

<table>
<thead>
<tr>
<th>Item being Completed</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Selection</td>
<td>January 6, 2008</td>
</tr>
<tr>
<td>Best Possible Design</td>
<td>January 8, 2008</td>
</tr>
<tr>
<td>Design of Gripper</td>
<td>February 1, 2008</td>
</tr>
<tr>
<td>Order Gripper Materials</td>
<td>February 5, 2008</td>
</tr>
<tr>
<td>Assembly of Gripper</td>
<td>April 4, 2008</td>
</tr>
<tr>
<td>Testing</td>
<td>April 25, 2008</td>
</tr>
</tbody>
</table>

The final design of the gripper was not finished until April 4, 2008, because of major design changes. The gripper was originally going to be a parallel jaw gripper and was redesigned into an angular jaw gripper. This delay caused the preceding deadlines to be late as well. The assembly of the gripper was finished on April 15, 2008, and the final testing was finished on May 15, 2008.

BUDGET

The preliminary budget shows the gripper costing $1500; this cost was 20% of the total arm. Instead of buying the gripper, a gripper was designed and the total cost after the design phase was $363. Table 3 shows the cost of the major components of the gripper. The gripper’s total cost was 6% of the total cost of the project. The total budget for the gripper can be found in Appendix E.

Table 5-Budget of Major Components

<table>
<thead>
<tr>
<th>Components</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servo Motor</td>
<td>$105</td>
</tr>
<tr>
<td>4 Spur Gears</td>
<td>$12 each</td>
</tr>
<tr>
<td>Aluminum</td>
<td>$155</td>
</tr>
</tbody>
</table>

CONCLUSION

This project was to build a prototype robot manipulator for FRR, which the company could then improve to make it marketable. FRR is very pleased with the gripper and arm and have stated that the project is 90% of the way to becoming marketable. They are pleased with all of the features that have
been incorporated into the arm and gripper. There are two changes needed for the gripper to make it marketable. The first change is adding a wireless video feed to the gripper so that the operator can visually see what it is gripping. The second change is using quick disconnects instead of screws for the adapter plate. This feature would enable the operator to change the end-of-arm tooling without the use of tools. Once these two changes are made to the current gripper design it will be ready for FRR to market.

REFERENCES

### APPENDIX A – RESEARCH

<table>
<thead>
<tr>
<th>Hero Robot</th>
<th><img src="http://www.firstresponserobotics.com/" alt="Hero Robot" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>This is the robot we are making the arm for</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oceaneering’s Terabot™</th>
<th><img src="http://www.oceaneering.com/spacesystems.asp?id=1276" alt="Terabot" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Good: tubular design for manipulator. All weather 5 degrees of freedom</td>
<td></td>
</tr>
</tbody>
</table>

- Oceaneering’s Terabot™ is a 5-degree-of-freedom, all electric manipulator with an electric or pneumatic gripper (or optional tool change end effector). Its design reflects Oceaneering’s 20+ year history designing and manufacturing equipment for use in the world’s harshest environments – space, the deep ocean, and desert. The Terabot has a 25lb. lift capacity throughout its full hemispherical envelope. Static and dynamic seals make it water and dust resistant and capable of withstanding intense rain, heavy dust, and short periods of full immersion. |

<table>
<thead>
<tr>
<th>IRobot</th>
<th><img src="http://www.irobot.com/sp.cfm?pageid=145" alt="IRobot" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Good: side mounted to robot tubular design for manipulator. all weather light weight</td>
<td></td>
</tr>
<tr>
<td>bad: camera mounted far away from gripper.</td>
<td></td>
</tr>
</tbody>
</table>

- Get situational awareness in hostage situations…
- Gain the tactical advantage on SWAT missions…
- Protect first responders and the community from danger…
Portable turner slips over the doorknob. Hand slides in the other end for a quick and easy way to open a door. Made of high-impact plastic. For right or left-handed use. Handle is 4½” long.

### Good:
One way to open doors.

### Bad:
This type of gripper would not be able to pick anything up.

---

### Interviews

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please, state your name and job title?</td>
<td>Mike Cardarelli, President CEO of First Response Robotics LLC.</td>
</tr>
<tr>
<td>Are you affiliated or somehow involved with operating, designing, and manufacturing any robotic devices? If yes, how long have you done this sort of work?</td>
<td>Yes. Have built seven robots since May, 2005</td>
</tr>
<tr>
<td>Does your robotic device have some sort of robotic manipulator or robotic arm? If yes, what kind of device it is?</td>
<td>Articulating arms on each wheel, each are independent and rotate 360°. Camera mechanism that can tilt and pan.</td>
</tr>
<tr>
<td>For what purpose does the HERO robot need a robotic manipulator?</td>
<td>For Police Department: to respond to hostage crisis situations to establish two way communications. For EPA: to collect soil, chemical samples as well as swab, pick, and open objects.</td>
</tr>
<tr>
<td>How many degrees of freedom does it have?</td>
<td>One DoF (clockwise, counterclockwise)</td>
</tr>
<tr>
<td>What do you view as the most significant problems facing the use of the robotic arms on UGV (unmanned ground vehicle)?</td>
<td>Weight, Dexterity, Size, Robustness of the design, and the amount of accessories that can be added to it.</td>
</tr>
<tr>
<td>What are the most important features the robotic manipulator should posses?</td>
<td>Gripper with the ability to open household door; camera attached to the gripper.</td>
</tr>
<tr>
<td>How would you improve the current design of your robotic manipulator?</td>
<td>The robotic arm must be light weight, compact, reliable, and easy to use.</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please, state your name and job title?</td>
<td>Keith Kowalski, President CEO of Robotics Research Corporation</td>
</tr>
<tr>
<td>Are you affiliated or somehow involved with operating, designing, and manufacturing any robotic devices? If yes, how long have you done this sort of work?</td>
<td>Incorporated in 1983. Prior to establishing his own company worked for SDRC lab. Worked on mechanical systems in the field of robotics for more than 25 years.</td>
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<tr>
<td>Does your robotic device have some sort of robotic manipulator or robotic arm? If yes, what kind of device it is?</td>
<td>Main product and services is a modular robot design, family of modules to form any particular manipulator design.</td>
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<tr>
<td>How many degrees of freedom does it have?</td>
<td>Have built up to seventeen degrees of freedom.</td>
</tr>
<tr>
<td>What do you view as the most significant problems facing the use of the robotic arms on UGV (unmanned ground vehicle)?</td>
<td>Lack of application knowledge and people do not know how to use it.</td>
</tr>
<tr>
<td>What are the most important features the robotic manipulator should posses?</td>
<td>Depends on application.</td>
</tr>
<tr>
<td>How would you improve the current design of your robotic manipulator?</td>
<td>Increase the dexterity of the arm. Be creative and do not stop improving. Use as many electrical components as possible and less hydraulics</td>
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APPENDIX B - SURVEY

Robotic Manipulator for HERO (Hazardous Environment Robotic Observer)

Customer Survey

We are, Sergey Zhemchuzhny and Jeremy Nugent, seniors at the University of Cincinnati studying Mechanical Engineering Technology. Our goal is to design and build the robotic manipulator for HERO (Hazardous Environment Robotic Observer). We would like you to take a few minutes and fill out this survey. By answering the questions below, we will be able to use your answers to build a better manipulator.

What is important to you for the design of a robotic manipulator? Please circle the appropriate number corresponding to each question. 1 = low importance 5 = high importance

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We would like to extend our gratitude to all responders for taking their time to participe in our survey

Appendix B1
### APPENDIX C – QUALITY FUNCTION DEPLOYMENT

#### House of Quality

<table>
<thead>
<tr>
<th>Features</th>
<th>Ability to replace gripper with another tool</th>
<th>Ability to hold torque in case of power loss</th>
<th>Ergonomic design of the OCU</th>
<th>Compact design in stowed position</th>
<th>Ability to assemble and disassemble links with ease</th>
<th>All materials weather resistant</th>
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<td>ft$^2$</td>
<td>slug-ft$^2$</td>
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## APPENDIX D – SCHEDULE

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Robotic Manipulator for HERO Robot  
(Mechanical)  
Jeremy Nugent
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### Robotic Manipulator for HERO Robot

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<td>Purchase 3-Axis Joystick</td>
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<tr>
<td>Fabrication of the Main Controller</td>
<td></td>
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<tr>
<td>Order Gripper Materials &amp; Tubing</td>
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<td>Assembly of Manipulator</td>
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<td>Testing of the Main Controller</td>
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<td>Testing</td>
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<td>Demonstration of proof of design</td>
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<td>Tech. Expo</td>
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<td>Oral Presentation</td>
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<table>
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<tr>
<th>Both</th>
<th>Sergey</th>
<th>Jeremy</th>
</tr>
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<tbody>
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Appendix D3
# APPENDIX E – BUDGET

<table>
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<tr>
<th>Part Description</th>
<th>Quantity</th>
<th>Manufacturer</th>
<th>Delivery/Lead time</th>
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<th>Total Cost</th>
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<td>Nylon Flange</td>
<td>6</td>
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<td>3 days</td>
<td>6294K203</td>
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<td>Metric 18-8 SS Cup Point Socket Set Screw M4 Size, 4mm Length, .7mm Pitch</td>
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<td>$10.03</td>
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<td>Gears</td>
<td>4</td>
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<td>7 days</td>
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<td>Servo Motor</td>
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<td></td>
<td>hitec hsr-5990tg</td>
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<td>8975K34</td>
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**Grand Total**

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<td>Gripper Components</td>
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<td>Arm Components</td>
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<td>$362.34</td>
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APPENDIX F – PROOF OF DESIGN

Product title:
Robotic manipulator for Hazardous Environment Robotic Observer (HERO)

Purpose:
Allow First Response Robotics’ Hazardous Environment Remote Observer to lift objects, to gain access through the doors, and to remove dangerous objects to a safer place

Special features:
Ability to easily replace gripper with another tool by using off-the-shelf gripper or adapter plate, lighter or similar in weight components (aluminum, carbon fiber, etc)

Need for product:
The ultimate customer (first response robotics) would like to see the arm to lift a five pound object at full extension (four Lbs is required by the government), to open door knobs, and to weigh less than fifteen pounds

Correlation with existing Unmanned Ground Vehicles in the field:
Some of the customer features named in the survey resembles similar characteristics in iRobot’s Pack Bot and Negotiator 6X by RoboticsFX. The following features are listed with how we intend to design them into our arm.

- all weather resistant
  - material specifications or protective enclosures
  - all fasteners are made out of stainless steel
- ability to hold torque in case of power loss
  - joints J2, J3, and J4 will have a power-off brake installed and interfaced with the main controller
- a compact design in stowed position
  - there will be 3 joints in the arm to enable it to fold
- ability to replace gripper with another tool
  - there will be an adapter plate mounted to arm and gripper

Physical requirements:
Round tubular profile for the robotic arms’ links; lighter or similar weight as robotic manipulator made by the iRobot, etc.; the length of the arm at full extension is 40in long per government specification

Service environment:
Materials used to manufacture the arm to be corrosion resistant; all fasteners are made out of stainless steel

Appendix F1
APPENDIX G – SUPPORT LETTER

First-Response Robotics, LLC.
4010 Bach Buxton Road
Amelia, Ohio 45102
Office – 513-752-6653
Fax – 513-752-6687

University of Cincinnati
College of Applied Science
2220 Victory Parkway
Cincinnati, Ohio 45206-2839

December 3, 2007

Muthar Al-Ubaidi,

First-Response Robotics, LLC would like to thank the University Of Cincinnati College Of Applied Science with the opportunity to work with your team on the robotic arm project.

Sergey Zhemchuzhny and Jeremy Nugent have shown an extremely high level of enthusiasm with this project. Since they are the primary design engineers, their contributions will not go without notice. First Response Robotics, LLC would like to donate our team with all manufacturing requirements needed in order to build the robotic arm for the “HERO” robot. This will include all materials, tooling and assembly work to complete the job. Included with this grant is the financial support needed to purchase necessary materials.

Mr. Zhemchuzhny and Mr. Nugent along with the University of Cincinnati will not be paid for their research and development. They will be acknowledged as the design engineers on this project but will not be awarded any rights for their designs. All rights and designs will be the property of First-Response Robotics, LLC.

The cost for materials will need to be approved by First Response Robotics, LLC. and assigned a purchase order number. We look forward to Tech Expo 2008 and will support your team with this project with the same amount of enthusiasm.

Sincerely,

Mike Cardarelli
President
First-Response Robotics, LLC.
APPENDIX H – MATERIAL SELECTION

ASHBY CHART

Young's modulus $E$ versus density for various materials
Strength versus density for various materials
## APPENDIX I – MATERIAL SELECTION

### WEIGHTED DECISION MATRIX

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<thead>
<tr>
<th>Property</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Positive Decision</th>
<th>Weighting factor wi</th>
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<td>4. Ductility</td>
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### Possible Design Combinations

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<th>Material</th>
<th>Go-no-go screening</th>
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<th>Cost</th>
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<td><strong>Material</strong></td>
<td>Machinability</td>
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<td>Weldability</td>
<td>Availability in tubing</td>
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<td>β</td>
<td>ksi</td>
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<td>S</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>0.285</td>
<td>22.8</td>
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<tr>
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<td>S</td>
<td>S</td>
<td>S</td>
<td>U</td>
<td>0.098</td>
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<td>U</td>
<td>S</td>
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<td>Ti-6Al-6V-2Sn Titanium alloy</td>
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APPENDIX J – DESIGN ANALYSIS

Von Mises Test

Factor of Safety Test
APPENDIX K – DETAILED DRAWINGS

ADAPTER PLATE

Top View

Bottom View

0.043

0.750

0.167

0.177

R0.079 THRU

0.375

2.000

0.250

1.250
DRIVING SHAFT
FINGER
Take Flange Bushing and cut 1/8" off of end.
GEARBOX FRONT PLATE
MOTOR BOX

Top View

Bottom View

<table>
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<th>DRILLING LOCATION SPECIFIED</th>
<th>HINT</th>
<th>GAGE</th>
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<td>GRIP</td>
<td>1/8&quot;</td>
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<tr>
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<td>CLAVITY</td>
<td>1/8&quot;</td>
</tr>
<tr>
<td>S1 HOLE 2 1/8&quot; Dјчж</td>
<td>TOU HOLE</td>
<td>1/8&quot;</td>
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Rev: A

Scale: 1:2

Weight:

Sheet 1 of 1

Appendix K10
MOTOR MOUNT CUT

Top View

2 x Ø 0.130 \( \pm 0.030 \)
M4x0.7 - 6H \( \pm 0.036 \)

0.197

Bottom View

2 x Ø 0.130 \( \pm 0.030 \)
M4x0.7 - 6H \( \pm 0.036 \)

0.216
MOTOR MOUNT

Top View

Bottom View

Appendix K12
NECK

Top View

2 x Ø 0.130 ≤ 0.551
M4 x 0.7 - 6H ≤ 0.394

Bottom View

Ø 0.157 THRU
Ø 0.315 ≤ 0.236
Ø 0.157 THRU
Ø 0.315 ≤ 0.197

Title:

A Neck

Scale: 1:1

Appendix K13
APPENDIX L – DETAILED ASSEMBLY DRAWINGS

GEARBOX ASSEMBLY

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<tr>
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<td>Ioler Shaft</td>
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<td>3</td>
<td>Gear</td>
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<td>4</td>
<td>Set Screw Gears</td>
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<td>Range Bushing Cut</td>
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<td>6</td>
<td>Gear Shaf for hub</td>
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MOTOR BOX ASSEMBLY

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COMPLETE ASSEMBLY

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