Mechanical Design of Biped Vision Hardware

Biorobotics and Locomotion Lab
Cornell University
05/19/11

Course Information
MAE 4900
Individual/Group Projects in Mechanical Engineering
3 Credits

Lab Advisors: Jason Cortell & Andy Ruina

Contact Information
Jon Kuriloff
Mechanical & Aerospace Engineering '13
E-mail: jonkur@gmail.com
Telephone #: 201-873-7348
Permanent Address:
0-22 Yost Place
Fair Lawn, NJ 07410

Table of Contents

Abstract

This document describes in detail the work that Jon Kuriloff conducted on hardware for the Cornell Ranger, a four-legged biped robot, in Andy Ruina's Biorobotics and Locomotion Lab at Cornell University in the Spring semester of 2011. Namely, the report addresses the motivation for enabling Ranger to steer itself autonomously and the design criteria associated with creating the hardware needed to accomplish this task. It then illustrates the design process and resulting manufacture of the necessary mechanical components for the robot, which include sensor boxes, a sensor mount, and leg clamps.

Background on Ranger

The Cornell Ranger is a four-legged biped robot that was conceived in Professor Ruina's Biorobotics and Locomotion Laboratory. The robot's design integrates mechanical and electrical components with computer control. It is powered by batteries and, as of the date of this paper, is steered by a human operator via a transmitter.
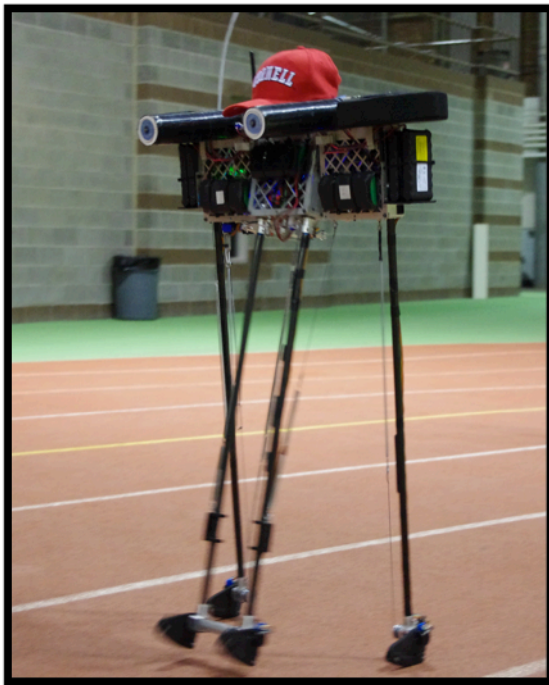

Figure 1: Cornell Ranger walking (*Photo credit: Nic Williamson*)

Mechanical Design of a Vision System

There is not definitive standard for what it means for a robot to be autonomous. One literal definition of the adjective explains it as "having the right or power of self-government" (Merriam-Webster Online Dictionary). In that regard, one could argue that there are no truly autonomous robots, as a

robot's behavior is dictated in some form or another by its programming and design. One can also recognize robots as having varying degrees of autonomy. With this perspective, it is generally considered a technological improvement, or even an achievement, to make a given robot more autonomous. In Ranger's case, the prospect of having the robot steer itself was desirable in that it would render it more autonomous. Not only would enabling Ranger to steer on its own be an impressive feat, but it would also stimulate interest in the robot and generate publicity for it. Additionally, and arguably most importantly, giving Ranger this additional degree of autonomy would provide positive implications for the success of a biped performing useful tasks in the future.

With the goal of autonomous steering in mind, it was necessary to develop a system that would allow Ranger to take in information about its surroundings and use it to navigate a path successfully. Since Ranger typically walks around a track, the approach chosen by the lab was to give Ranger visual information via color sensors such that it could detect where it was at a given time with respect to the track. Implementing something on Ranger that could perform these tasks required that color sensors be mounted to the robot by means of some sort of apparatus.

Associated with creating a mechanical setup for enabling Ranger to gather visual information were a number of design objectives. Its main two functions were to house the color sensors and to attach to Ranger, in suitable fashions. One of the design requirements was that the color sensors be situated a certain distance from an optical lens, such that light wouldn't enter from anywhere but the lens (see illustration below). This meant that the area between the sensor and lens must be completely black. These operating conditions would ensure that the light sensor would obtain accurate color readings from the track on which Ranger walked. In addition to this constraint, the apparatus was to be designed such that it was as lightweight as possible, sturdy and vibration-free. The lighter such an apparatus would be, the less it would interfere with the dynamics of Ranger's walking when Ranger swings its legs. Finally, it had to be designed such that it would not get in the way of any of Ranger's other mechanisms.
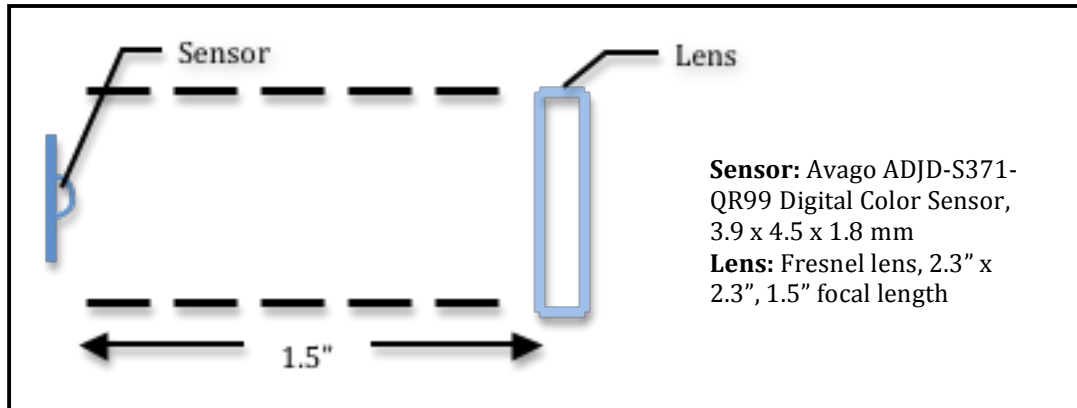
`

Figure 2: Illustration of sensor setup

Sensor Box

One method of meeting the above design criteria was to create or purchase some sort of box that could house the light sensor on bottom, surround it on all sides, and attach to the necessary lens on top. Buying a commercially available box that could perform these functions would save time and effort, whereas creating and manufacturing a box would save considerable mass. The design approach chosen initially was to create a sensor box from scratch, with the hopes of minimizing mass as much as possible.

A CAD drawing of the sensor box design, made with Autodesk Inventor 2011, is shown in Figure 3 below. Its overall dimensions are 2.3" x 2.3" x 1.6", where 2.3" x 2.3" represents the area of the lens to be attached onto the box, and 1.8" represents the distance needed between the sensor and the lens. The wall thickness is 1/16", minimizing the amount of materials used while keeping the box strong. Fillets at each of the box's inner corners prevent stress concentrations and provide room for holes. The holes, in identical locations on either side, enable the mounting of the color sensor on one side and the lens on the other. A rib running down the center of one of the walls provides rigidity. Two holes in this rib provide a place for the sensor box to attach to the rest of the mounting apparatus, which will be discussed later in this report.
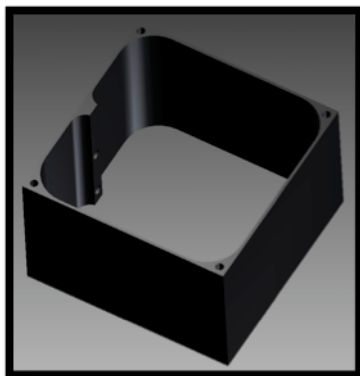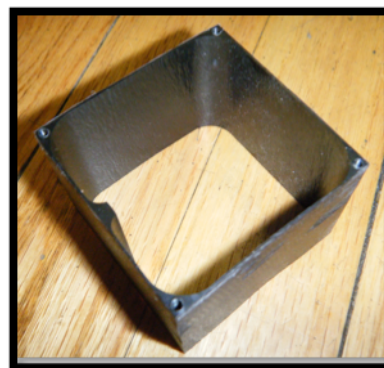

Figure 3: CAD model of sensor box

Figure 4: Manufactured Sensor Box

5

The material selected for the box was Delrin, a brand of acetal resin. This material was well suited for the job because it has a high stiffness to weight ratio and is also black, thereby eliminating the need for any additional work making the inside of the box black. The sensor box was designed to be CNC machined out of a solid block of Delrin, cutting out material using a 1/4" diameter end mill. The toolpath for this operation, created with AutoCAD 2011, is shown in the appendix to this report (Figure A3). This was done by means of inputting the sensor box CAD file from Inventor and then, with the box oriented such that the face that would be cut from is up, offsetting the drawing's lines by the tool radius of 1/8".

In order to implement this toolpath for the CNC mill in the Biorobotics Lab, it was necessary to devise a text file compatible with GCODE that, when run, would machine the desired part. Writing such a program required knowledge of several basic GCODE commands. Table 1 below offers a summary of the commands used. This list of commands sufficed to create a program that would cut out the desired box in passes of .05". For the sake of clarity, the program itself is not included in this report. Simulating the code's output with an NC Code simulator depicted the expected toolpath, shown below in Figure 5. This gave promising results for machining the sensor box successfully.

GCODE Command	Description
G0X__Y__Z__	Rapid mode to listed coordinates
G1X__Y__Z__	Coordinated motion (use when cutting) to the listed coordinates
G2,G3X__Y__I__J__	Coordinated helical motion (CW & CCW) to listed X and Y coordinates in an arc with its center at listed I and J coordinates
G90	Absolute distance mode
G91.1	Sets arc centers I,J,K relative to the arc's starting point
F	Set feed rate of tool
M2	End program

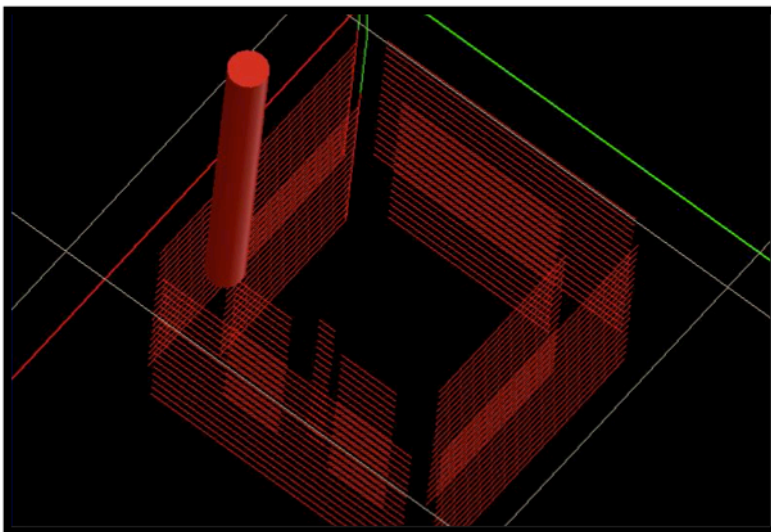Table 1: Description of Relevant GCODE commands

Figure 5: Simulation of toolpath, produced with the freeware *NCSim* based on inputted GCODE.

Machining setup entailed mounting Delrin stock on a plastic slab with double-sided tape, facing the stock to the desired height of 1.6" on a mill, clamping the stock down on the CNC mill base, and zero-ing the 1/4" end mill to the desired location on the face of the stock. In the program's first trial, the tool cut all the way to the bottom of the Delrin stock, resulting in brittle fracture of the part. Running the program again yielded a partially successful part; the part did not fail in any way, and the remaining stock from the last pass was cut off easily, but the walls of the box were unfortunately thinner than designed for. This apparent machining flaw can be attributed to vibrations from the long end mill as it made passes, causing it to take off more material than expected. As a precision operation, this impacted the structural integrity of the box, making it too flimsy for its purposes.

Sensor Mount

In light of the difficulties posed with trying to machine a lightweight sensor box, as well as the effort involved, it was the lab's decision to proceed using a commercially available box. However, the box itself only addressed some of the mechanical design objectives for giving Ranger vision. It was still necessary to design and manufacture an apparatus for mounting one or more sensor boxes to Ranger. Such an apparatus would have to prevent any movement or vibration of sensor boxes as the robot would walk, be as lightweight as possible and not interfere with the robot's other mechanisms in any way. It was soon recognized that the easiest place to situate such a device would be on one of Ranger's outer legs. The design of a controller that would take information from light sensors and adjust Ranger's trajectory accordingly dictated that there must be one sensor pointing in front of Ranger and another sensor pointing in the opposite direction. Also, since it was not definitive where on Ranger's leg the apparatus would be located, as well as at what angle the sensors should be pointed to get the best results, it was important that the design be adjustable.

With these goals in mind, brainstorming, drawings and design development yielded the final design below (Figure 8). Assembly and attachment to Ranger's leg is illustrated in Figure 6. This design features a bent aluminum plate, two "clamps" made from Delrin, and two reinforcing strips of aluminum. The two sensor boxes mount to the two bent faces of the aluminum plate. The four holes on each face allow for three possible configurations of the sensor box. By aligning the second hole on the sensor box with one of the three holes in a circular arc on the plate, the sensor box can be positioned at an angle of 30, 45 or 60 degrees from the horizontal. The two leg clamp pieces clamp together around Ranger's leg with screws that go through one end and thread into the other. Two reinforcing strips of aluminum prevent vibration of the bent faces of the sensor mount.
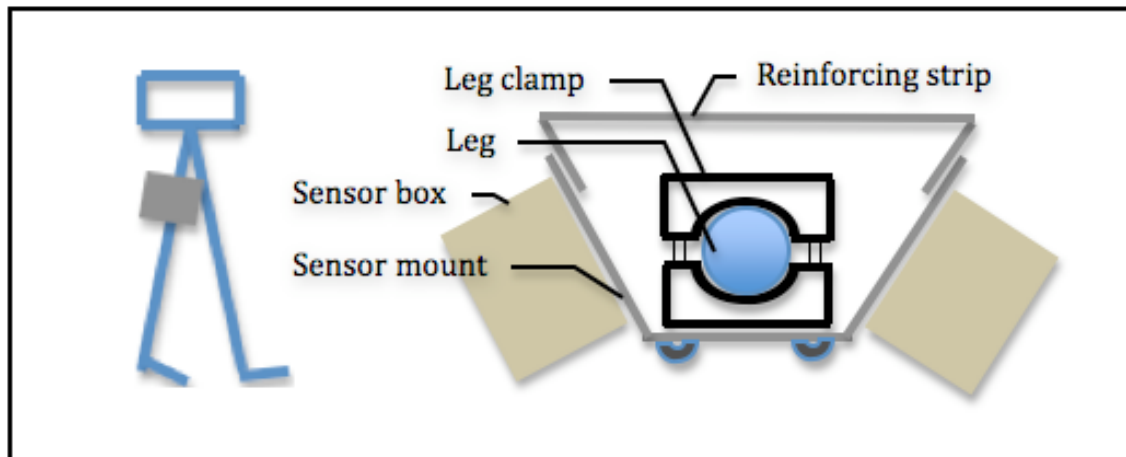
Figure 6a: Attachment of apparatus to Ranger's leg (left)
Figure 6b: Assembly of sensor mount, clamped to leg (right)
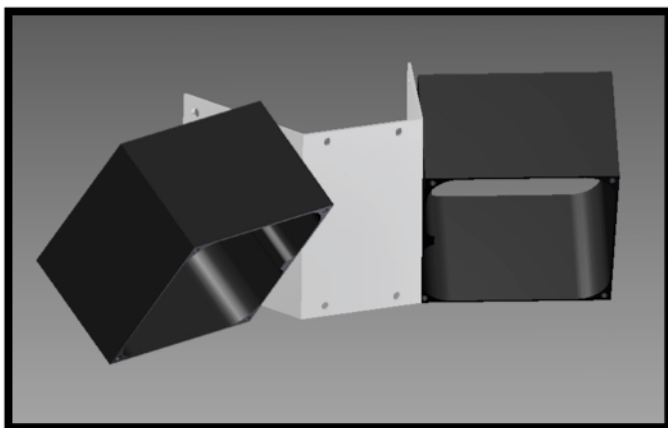

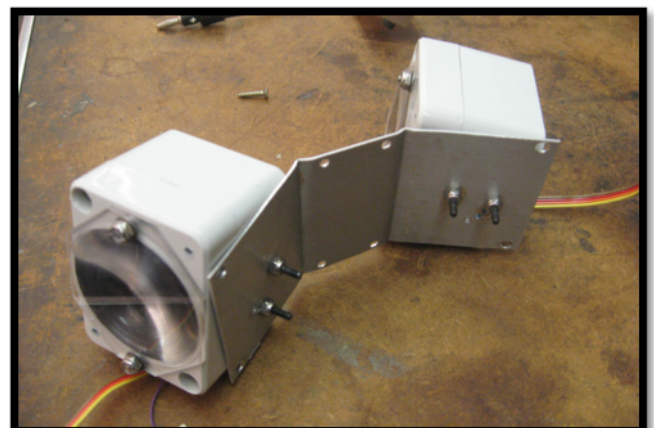Figure 7: CAD of Sensor Mount & Boxes

Figure 8: Manufactured Sensor Mount & Boxes

Two sets of leg clamps attach the sensor mount to the robot's leg (Figures 9&10). A detailed drawing for the leg clamp can be found in the appendix of this report. The material used for this part is Delrin. The following is the procedure followed to machine this part:

1. Cut out a square from stock of the desired thickness using a bandsaw or hacksaw
2. Mount part in mill and face to size
3. Drill two tap size holes through the part in the designated locations
4. Bore out the middle hole to size using a boring tool
5. Cut part in half using a jeweler's saw
6. Tap holes on one half of the part
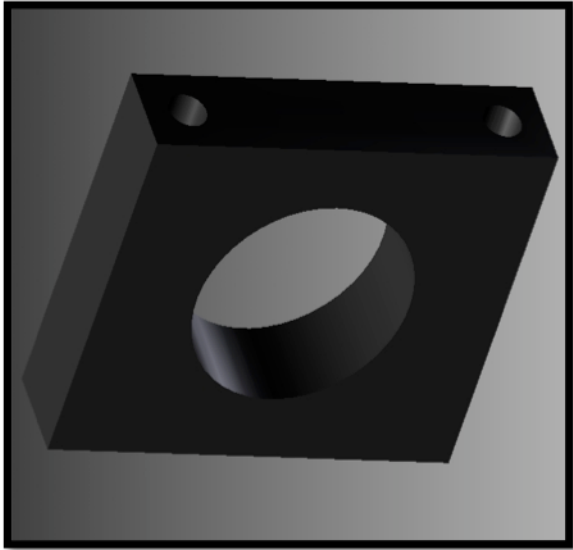7. Drill out to clearance size on the other half of the part

Figure 9: CAD model of leg clamp

Figure 10: Manufactured leg clamp

The reinforcing strips of aluminum attach to the corners of the sensor mount plate with screws and nuts. Manufacture for the two strips was quick and simple. It involved cutting metal strips with shears, drilling holes on either end with a hand drill and then bending both ends using clamps and a hammer (Figure 11). No drawing was made for the reinforcing strips. Lab manager Jason Cortell machined the two sensor boxes and the sensor mount itself.   A drawing for the sensor mount can be found in the appendix of this report.
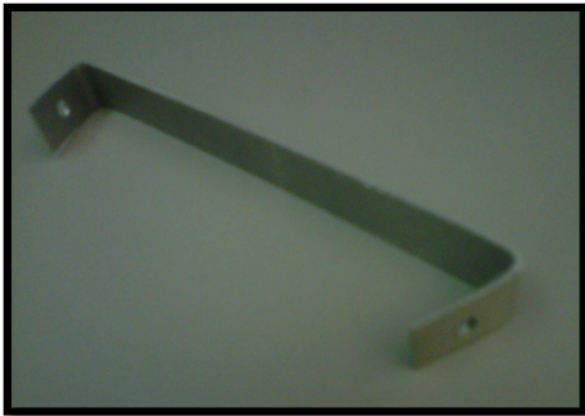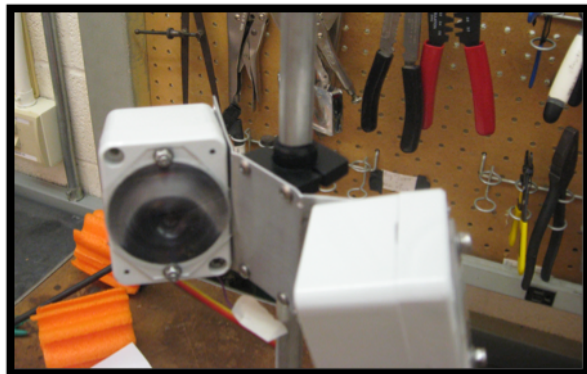

Figure 11: Reinforcing strip of aluminum

Figure 12: Full assembly with clamps

Conclusions

This report has summarized the fundamental goals behind designing mechanical hardware for a vision system on Ranger. It documented the design process by which such designs were conceived, developed and manufactured. To date, the Cornell Ranger is steered by remote control, as successful implementation of a vision system has yet to occur. This is largely due to difficulties that arose trying to distinguish between different colors on Ranger's path. Varying shades and light conditions prevent the sensor from making necessary distinctions between color readings. The sensors have since been tested in the sensor boxes and mounting apparatus, and everything functions as it should. Currently, there is not more mechanical hardware work planned for the vision system. Further implementation of successful autonomous steering for Ranger would require devising a control to properly understand data from the color sensors, or pursuing the use of navigation via GPS.

References

"Autonomous." *Dictionary and Thesaurus - Merriam-Webster Online*. Web. 19 May 2011. <http://www.merriam-webster.com/>.

"MachineMate Inc - Full List of CNC Codes." *Power Automation America*. Web. 19 May 2011. <http://www.machinemate.com/FullListCodes.htm>.
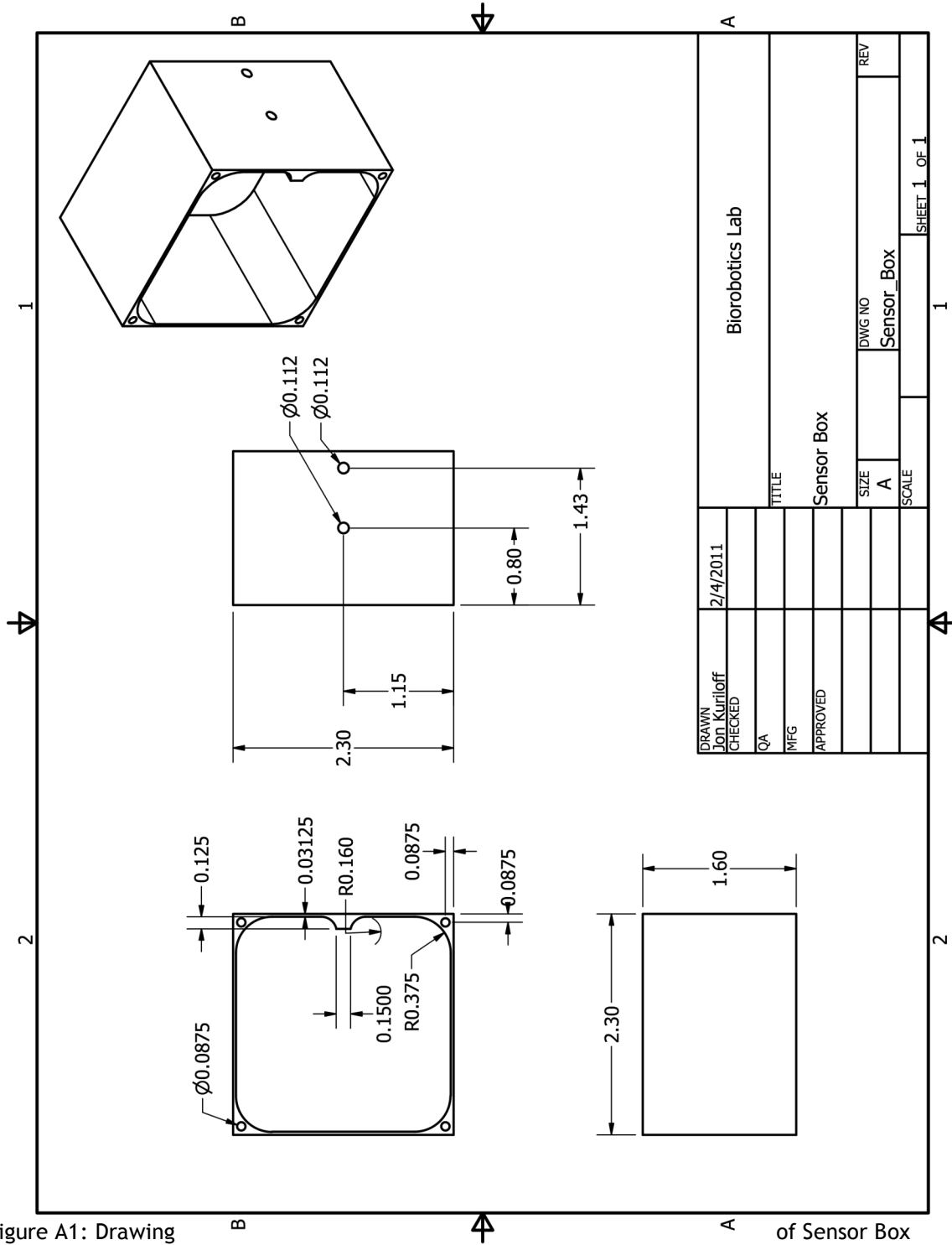
Appendix

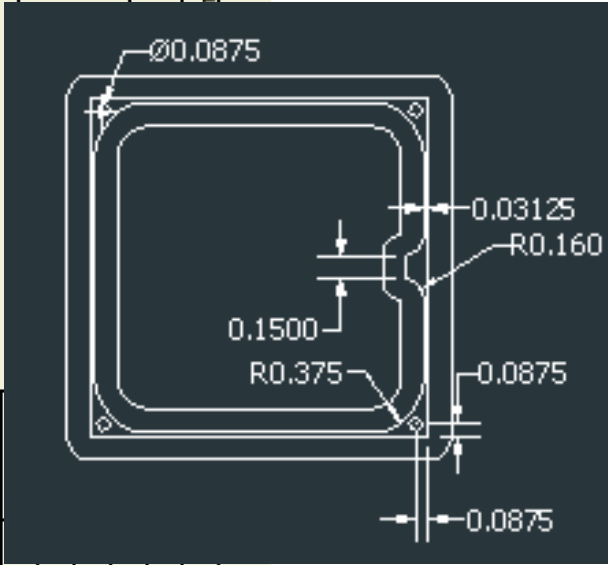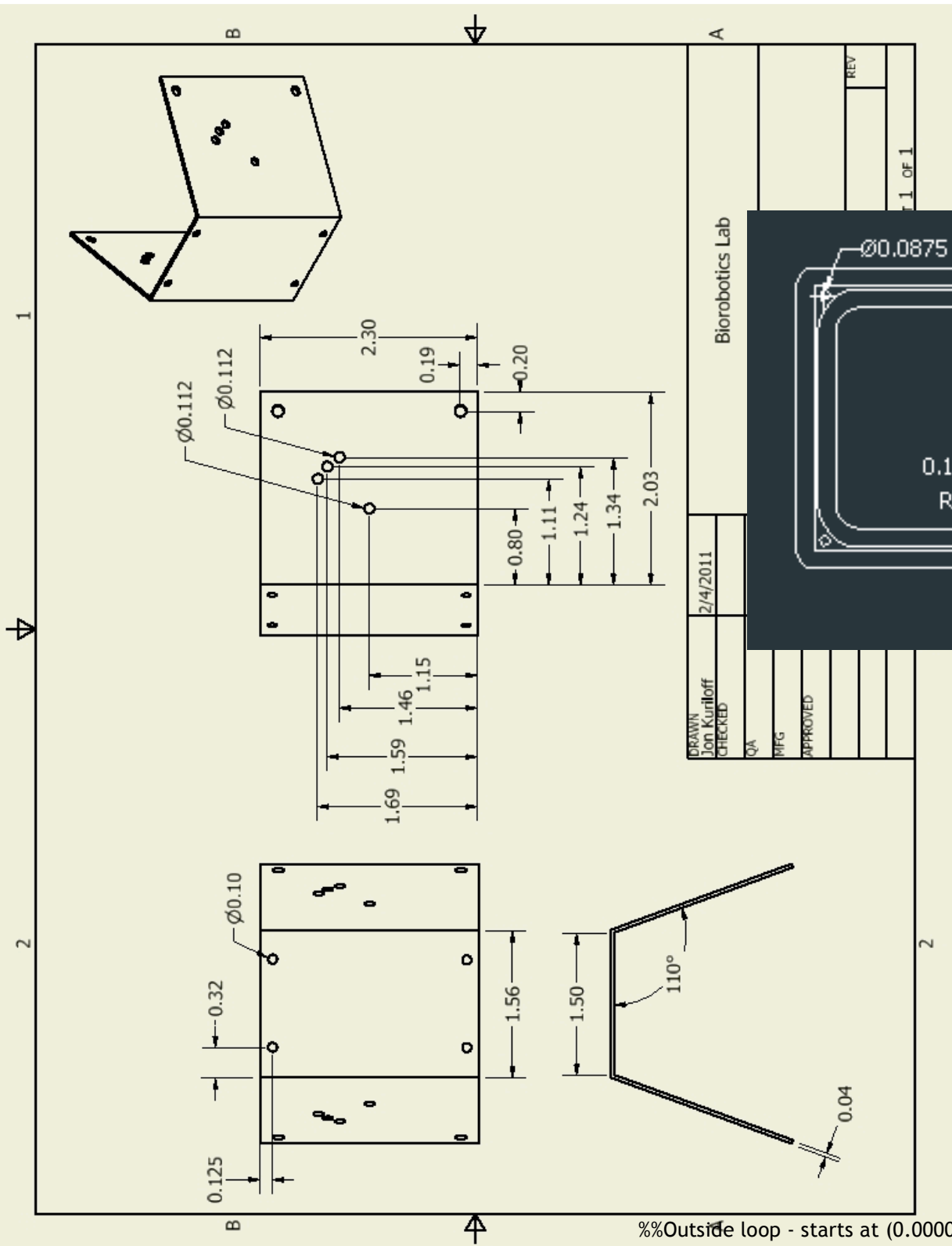Figure A1: Drawing of Sensor Box

Figure A2: Drawing of Sensor Mount

Biorobotics Lab

1 of 1

REV

DRAWN
Jon Kuriloff
CHECKED
2/4/2011
QA
MFG
APPROVED

Ø0.0875

0.03125
R0.160

0.1500

R0.375

0.0875

0.0875

2.30
0.19
0.20

Ø0.112
Ø0.112
Ø0.112

0.80
1.11
1.24
1.34
2.03

1.15
1.46
1.59
1.69

Ø0.10

0.32

1.56
1.50

110°

0.04

0.125

Figure A3:

%%Outside loop - starts at (0.000000,-0.156250)

Drawing of CNC mill toolpath for sensor box

%Pass 1 - 0.05 inches plunge depth

%%Inside loop - starts at (0.406250,0.187500)

%Pass 1 - 0.05 inches plunge depth

G0X0.406250Y0.187500Z0.000000

```
G0X0.000000Y-0.156250
G1Z-1.050000
X2.300000
G3X2.456250Y0.000000I0.000000J0.15625
G1Y2.300000
G3X2.300000Y2.456250I-0.156250J0.000000
G1X0.000000
G3X-0.156250Y2.30000I0.000000J-0.156250
G1Y0.000000
G3X0.000000Y-0.156250I0.156250J0.000000
```

12

```
G1Z-1.050000
X1.893750
G3X2.112500Y0.406250I0.000000J0.218750
G1Y0.918625
G3X2.109570Y0.922284I-0.003750J0.000000
G2X1.987500Y1.074750I0.034180J0.152466
G1Y1.224750
G2X2.109570Y1.377216I0.15625J0.000000
G3X2.112500Y1.380875I0.003750J0.003659
G1Y1.893750
G3X1.893750Y2.112500I-0.218750J0.000000
G1X0.406250
G3X0.1875Y1.89375I0.21875J0.000000
G1Y0.406250
G3X0.406250Y0.187500I0.218750J0.000000
```

Figure A4: Excerpt of GCODE used to CNC mill the sensor box. These blocks of code were iterated while incrementally increasing the plunge depth of the tool.