Modification of Steering System to Four-legged Biped

By: Yingyi Tan
yt229@cornell.edu
(Created 05/18/07)

Current Address: 909 East State Street
Ithaca, NY 14850
Tel: 607-342-4369

Permanent Address: 15 Merryn Road
Singapore 298464, Singapore
Tel: +65 96516214

Final Report for M&AE490, Independent Research Project

ABSTRACT

This paper details the modification of a steering system currently installed on the Cornell Ranger robot. This new steering system had to provide feedback to the computer and user. Conceptual designs were suggested to meet the needs of the problem and the detailed design is a more thorough and finalized version of the selected conceptual idea. Fabrication was carried out and the new steering system was implemented on the robot. The system was tested by walking the robot in various locations. Revisions were then made to the system based on the results of the tests. The final system was then evaluated against the specifications and suggestions for improvements are given.

1. INTRODUCTION

The Cornell Ranger, a 4-legged biped robot was built in fall 2006. The objective of the robot was to break the record for the longest distance walked. The target distance set then was 10km. The only possible and appropriate location for such a long distance walk was the indoor track at Barton Hall. As such, the robot had to be able to manipulate the 25m radius turn of the track and a steering system had to be implemented into the robot.

However, the Ranger was built to be as symmetrical as possible. This allows for greater stability in order to achieve long distance walks. Hence the 2 inner feet were constrained to move together while the outer feet are controlled such that they swing out to the same angle at the same velocity. This prevents the robot from moving sideways.

Steering was built upon the idea that a break to this symmetry would cause the robot to turn. The use of a rocking, orbital motion achieved this state of asymmetry. By holding the 2 outer feet at different angles respective to the horizontal position, the robot would rotate a little around the vertical axis and turn as a result. If one of the feet were held slightly lower than the other, the area of contact between the foot and the ground would be larger than the higher foot. This causes the lower foot to move slower than the upper foot. The smaller velocity will result in a smaller path traveled by the lower foot than the higher foot and hence the robot will rotate slight about the vertical axis of the slower foot and turn in the direction of the lower foot.

This mode of steering was accomplished via the use of a servo motor that had a gear attached to its end. A larger gear was attached to this smaller gear. A pulley was fixed eccentrically on the larger gear and hence when the gear rotated, the pulley (See pulley 1 in Figure 1 below) moved. Cables connecting the foot to each other were wound around the pulley. By rotating the gears in a certain direction, pulley 1 would move to a new position and the length of the cable would change, thus pulling the foot up or lowering it down. The stops in the RC servo motor were removed to allow the small gear attached to the motor to turn continuously. This was done to increase the range of angular motion of the large steering gear to at least 180 degrees so the robot could manipulate the turn in Barton Hall. Figure 1 shows the current steering system on the robot.

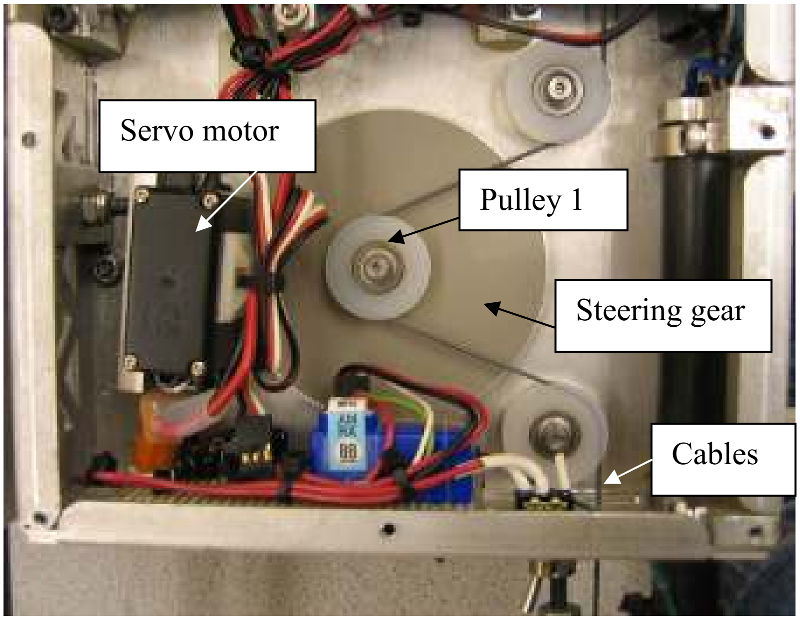


Figure 1: Current Steering system on robot showing gears, servo motor and pulley [1, 19]

This steering system was successful in manipulating the robot around the indoor track of Barton Hall. However, the large gear in this system turned continuously when the remote control was turned on. Thus, the only way of knowing which direction the robot was moving was by physically observing the robot and the position of its left foot. A new steering system that allowed the computer and hence user to know the heading of the robot without physically observing it was desired. Furthermore, by allowing the computer to know the position of the foot when the robot turns allows for greater symmetry. Currently, for the robot to turn left, the left foot moves down with respect to the horizontal. The foot moves up for the robot to turn right. Through appropriate programming, the robot can be made to move its right foot up in order to turn left instead, introducing greater symmetry. Also, the computer can automatically and simultaneously adjust the other parameters while the robot is turning to improve its walk in the turn.

This paper documents the modification of this steering system in order to provide feedback to the computer. The conceptual designs, needs and specifications of the design are mentioned in Section 2. The final detailed design is described in Section 3. Section 4 discusses the modeling, material acquisition and fabrication of the design. Section 5 summarizes the testing and revisions to the steering system. Section 6 evaluates the results of the test and the design. Further suggestions and discussions are given in Section 7.

2. DESIGN SPECIFICATIONS

2.1 Problem Statement

Modify the current steering system on the Cornell Ranger, a 4-legged biped robot, to incorporate feedback to the RC servo motor and increase the reliability of the system.

2.2 Objectives and Needs

The new steering system has to meet the following needs:

- Must allow the Ranger to have a turning radius smaller than the radius of the Barton track (25m). [1, 2.09]
- Must provide a constant feedback to the RC servo motor and computer.
- Must allow the robot to maintain the same heading when the steering system is turned off.
- Must be compatible with the current steering electronics already on the robot.
- Must be able to correct for the drift in alignment between the outer feet on the robot.
- Must be light, as any significant weight would affect the mass distribution and balance of the robot.
- Must be reliable and robust.
- Must be inexpensive and relatively quick to fabricate.
- Must not draw significant power from the batteries.
- Must be easy to repair and replace.

2.3 Evaluation Criteria

A set of specifications can be worked out based on the qualitative needs stated above. This set of specifications given in Table 1 below, can then be used to evaluate the various designs and to select the design that best meets the needs of the problem.

Specification	Target Value
Max power drawn	< 2W
Voltage drawn	3V
Mass	<50g
Dimensions	<6.5" x 4.5" x 2"
Cost	< $100
Fabrication Time	< 3 weeks

Table 1: Specifications

2.4 Concept Generation

Several designs of a steering system with feedback control were suggested and looked into. All these designs allowed for easy modification to the current system and complied with the needs of the problem statement. The suggested designs can be classified into two main categories:

- Potentiometer
- Magnetic Field Angle Sensor

2.4.1 Potentiometer

The cheapest and least complex design of the three, a potentiometer can be used to sense the angular displacement of the steering gear shown in Figure 1. This gear is used to adjust the length of the cables that are attached to the rear of the robot's feet. Using the handheld radio steering controller that comes with the servo motor, one can adjust the direction and magnitude of the angular displacement of the small gear attached to the servo motor's axis, which in turn adjusts the large steering gear. A pulley mounted eccentrically on the large steering gear causes the length of the cable to change correspondingly. Rotating the gear anticlockwise will shorten the length of the cable, pulling the front of the left foot down with respect to the horizontal and inducing a left turn on the robot as seen in Figure 2. The opposite happens when the gear rotates clockwise, pulling the front of the left foot up with respect to the right foot and resulting in the robot turning right.

In the current steering system, the computer is independent of the steering system. It does not know which direction the robot is heading or which way it is set to move.

The use of a potentiometer mounted on the rotational axis of the steering gear would allow the computer to know the angular displacement of the steering gear, from the angular displacement of the shaft of the potentiometer. The resistance of the potentiometer, which is proportional to the voltage across its ends, is proportional to its angular displacement. The RC servo motor sends the appropriate voltage across its end and simultaneously sends it back to the computer. Thus by assuming a linear relationship, one can deduce the difference in angles between the 2 outer feet.

Through appropriate programming, the robot's left foot would no longer have to move down with respect to the horizontal when turning left. Instead, when the computer senses a change in the voltage sent to the RC servo motor, it automatically moves the right foot up instead. This allows for greater symmetry and stability of the robot. Furthermore, by simultaneously changing certain parameters, the robot can be made to have a more stable walk while turning.

However, in order for a potentiometer to work effectively, its housing would have to be held stationary while its shaft is allowed to rotate freely. The following concepts were suggested:

Figure 2: Steering left, shortened cable length [1, 20]

Torsion Springs

Since the pulley was mounted eccentrically on the steering gear, it was allowed to move linearly in the horizontal direction. Linear motion of the entire potentiometer would have to be accounted for if it were attached onto the central axis of the pulley. This could be accomplished by attaching a torsion spring to a bracket holding the housing of the potentiometer, and to a flat stop. By securing the potentiometer housing tightly to the bracket, rotational motion could be prevented while at the same time allowing linear motion to take place.

However, this design had several shortcomings. There was limited space within the left hip box. There would be insufficient space to properly input a stop, spring and bracket without affecting the functions of the steering electronics and current gear and pulley system.

Secondly, there was a problem of attaching the potentiometer's shaft to the head of the pulley screw. The head of the screw was small and attaching the potentiometer reliably to it would present a problem as the potentiometer and its bracket would be considerably heavy.

Figure 3 shows a rough schematic of this design.

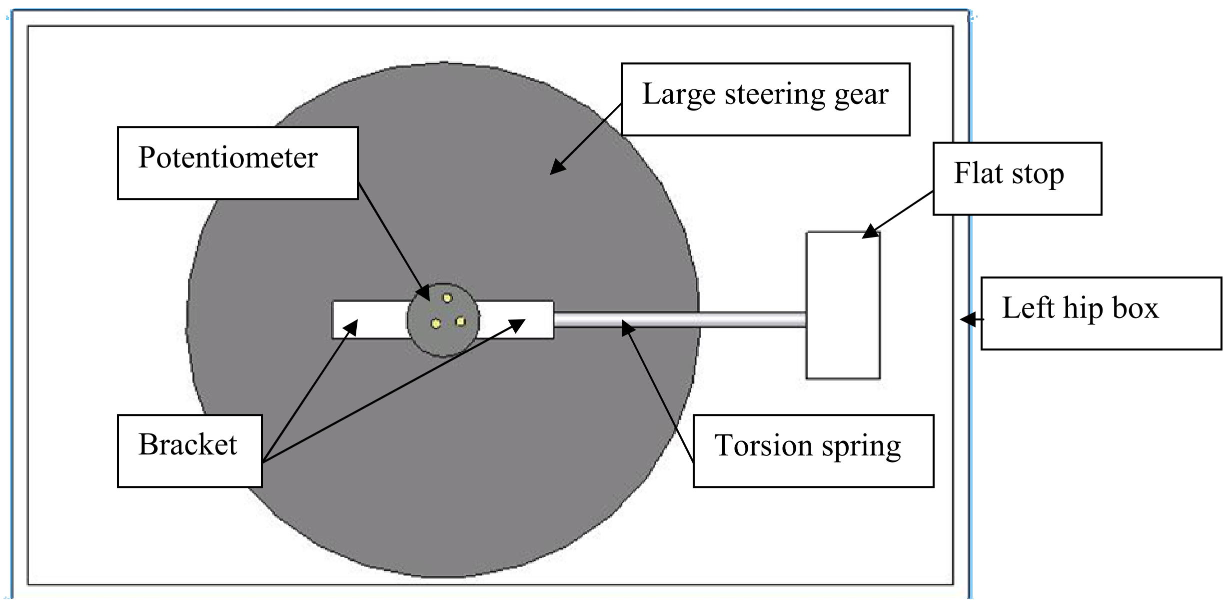


Figure 3: Torsion spring attached to potentiometer housing

Scotch Yoke

A scotch yoke –like mechanism could be constructed to hold the potentiometer in place. By drilling a hole into a rectangular flat plate and attaching a side of the plate to a pivoted lever, the potentiometer housing could be held stationary while the shaft rotates and the entire potentiometer moves linearly. The scotch-yoke design is shown in Figure 4.

This design also had its drawbacks. Blocks would have to be built into the hip box to hold the bars of the scotch yoke. The limited empty space within the box and steering electronics impeded the building of such blocks and the placement of the scotch yoke.

Secondly, the flat plate had to be manufactured to allow the housing to move linearly while holding preventing rotational motion. This required complex machining that was also not practical for this purpose.

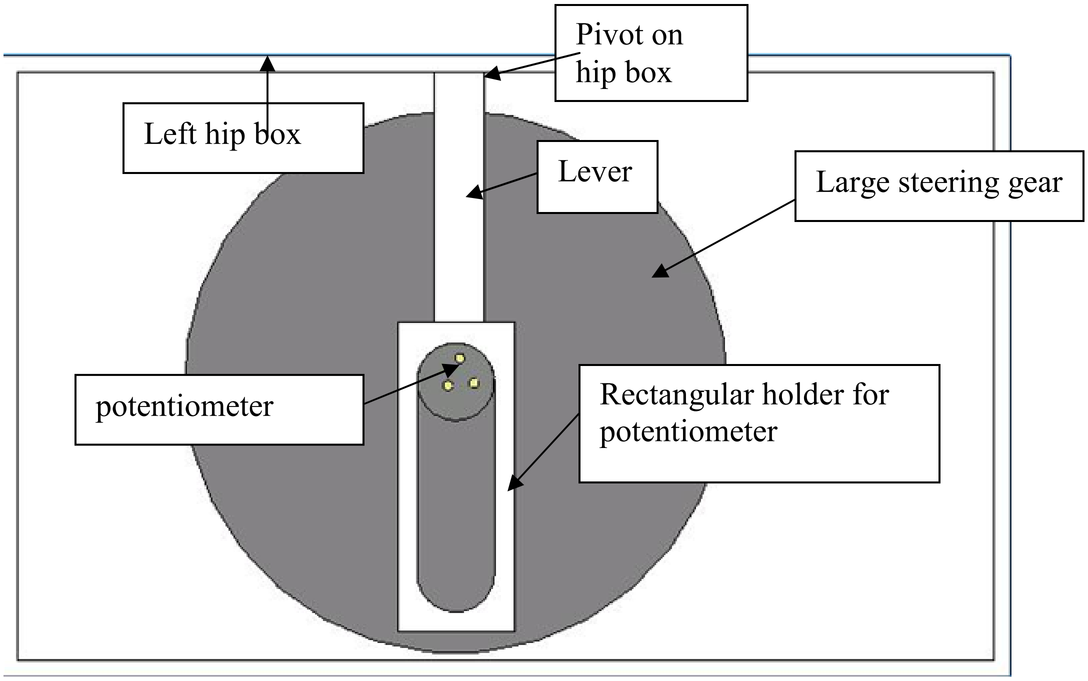


Figure 4: Scotch-Yoke design

Collars

The current steering system utilizes a screw that holds the gear hub extension and bearings to the gears and pulleys within the left hip box as can be seen in Figure 5. This screw is concentric with the steering gear and rotates with it. Attaching the potentiometer to the head of this screw will eliminate the need of allowing linear motion of the entire potentiometer since the screw does not translate.

Several methods were suggested in attaching the potentiometer shaft to the screw head:

- Shaft collars (Figure 10) – The shaft collar will have to be of different diameters on either side to account for the difference in diameter of the screw head and potentiometer shaft.

- Hex rod with adjustable shaft adapter – A hex rod can be inserted into the screw head and an adjustable shaft adapter could be used to connect the rod to the potentiometer shaft.

- Hex nut with clamp-on shaft adapter – A hex nut could be inserted into the hexagonal screw head and the closed end of the shaft adapter could be screwed into the nut. The open-end of the shaft adapter could be clamped around the potentiometer.

The use of ready-made shaft collars and hex rods had to be reconsidered since shaft collars of the right-size for the potentiometer's shaft were not easily available. Also, a bracket that attaches to the potentiometer's housing will have to be made in order to prevent it from rotating.

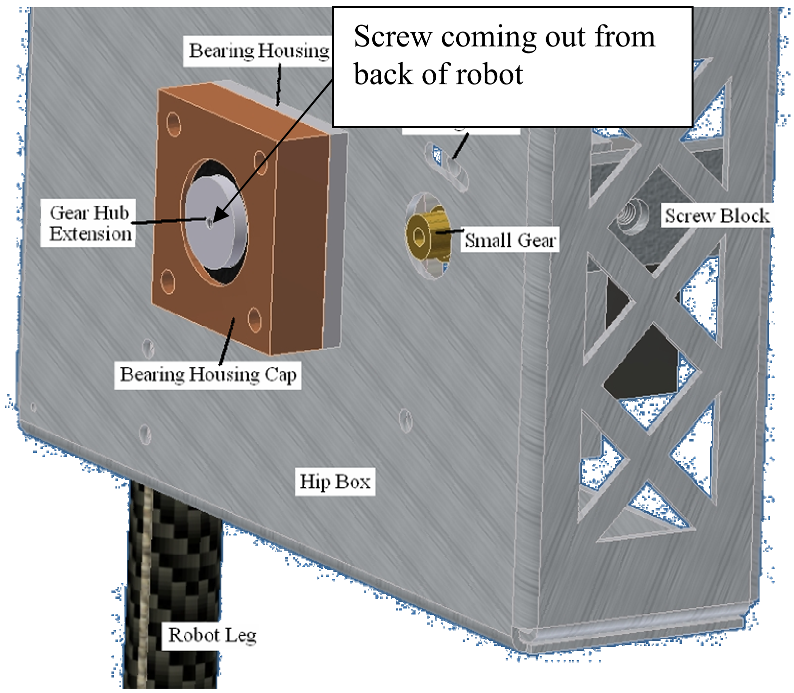


Figure 5: Isometric View of current steering system from back [1, 17]

2.4.2 Magnetic Angle Sensors

Programmable angle sensors that are used in the automotive industry such as those in Figure 6, could be implemented into the robot. These sensors rely on disturbances to the magnetic field in which the sensor is placed. The current through the sensor varies with the angle between the magnetic field and direction of current flow. [2,1] Such magnetic sensors are already pre-programmed and all that is required would be to input the zero angle and maximum displacement angle. The analog output signal can then be easily converted into digital readout by the computer.

However, the magnetic angle sensors are overly expensive and have to be compatible with the current electronics in the robot. Although the difference between the required supply voltage and the battery voltage can be easily adjusted for, other complexities in programming the sensor still exist. Another drawback to the use of such sensors is the need to create a magnetic field on the steering gear. Undesirable interaction between the magnetic field and electronics might occur as a result.

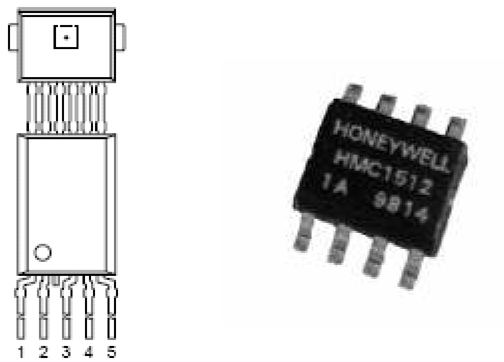


Figure 6: Magnetic Angle Sensors [3], [2, 1]

3. DETAILED DESIGN

After the initial designs and ideas were laid out, a detailed CAD drawing was created for it. However due to stresses in the current steering system, mechanical failure resulted and more modifications had to be made which were unplanned for. (See Section 5 for more details)

3.1 Functionality Overview

Due to the various drawbacks of the magnetic angle sensor mentioned above, the potentiometer design was chosen. The potentiometer was relatively cheap, easy to fabricate and could be easily implemented into the current electronics and steering system without any adverse effects to the system.

The RC servo motor of the current steering system is shown in Figure 7. It comes with a factory installed variable resistor. This variable resistor would have to be removed and replaced by an external one for ease in mounting and changing the angular position of the large steering gear. The potentiometer would have to be wired to the circuit board in the servo motor and the board rewired back to the motor itself. Before the potentiometer could be implemented into the steering system, tests would first have to be done to ensure that the potentiometers available in the laboratory were compatible with the servo motor. (See section 3.3) The tests would also determine the wiring of the potentiometer to the board and from the board to the motor. A board taken from a similar motor is pictured in Figure 8.

Figure 7: Servo motor used in the steering system.

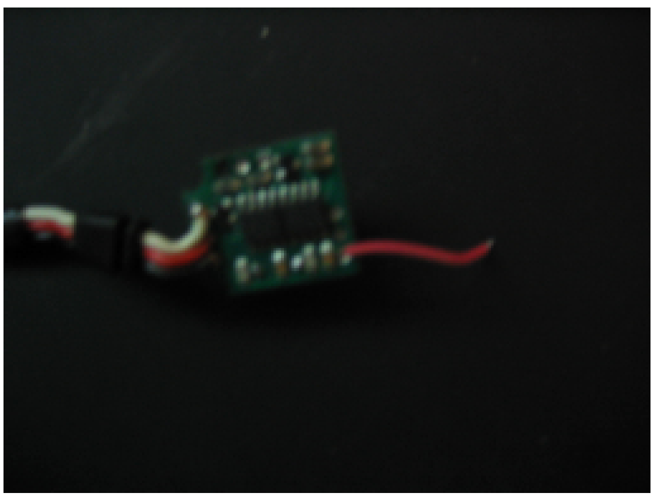


Figure 8: Circuit board in servo motor.

The potentiometer's housing has 3 leads. 1 is connected to the positive voltage supply, the 2nd to ground and the last lead is connected back to the RC servo motor and microcontroller. This provides the feedback to the computer. Since the voltage across the potentiometer's leads varies according to the angular displacement of the housing, this signal tells the computer the voltage that is being applied across the leads of the potentiometer. The voltage can then be converted into angles by reading the voltages at the 2 extreme positions and interpolating to find the corresponding angle of the foot.

In order for the potentiometer to work reliably, its housing would have to be fixed to the hip box. Use of a bracket that is screwed onto the hip box and connected to the housing would prevent its rotation. Such a bracket would have to be small and light so as not to affect the mass distribution on the robot.

3.2 Design Overview

As discussed in Section 2.4.1, several methods of attaching the potentiometer to the system had been suggested. Due to the complexities and difficulties in implementing the torsion springs and scotch yoke systems, which allowed linear motion of the entire potentiometer while constraining rotational motion of the housing, it was decided that the potentiometer should be attached to the screw head on the back of the hip box instead.

As mentioned in Section 2.4.1, there were several ways of attaching the potentiometer to the screw head. However, concerns were raised regarding the concentricity of the hexagonal recess on the screw head. As a result, it was decided that a shaft collar attached to the outside of the screw head would be a better choice over using hexagonal rods that would fit in the screw head.

One end of the shaft collar would fit around the screw head while the other end would fit around the potentiometer's shaft. The screw head had a wider diameter than the potentiometer's shaft and hence shaft collar of adjustable width on both ends had to be used. However, the bores of the adjustable shaft collars that were being sold were too large for the potentiometer's shaft. Hence a shaft collar would have to be specially machined. The bore diameter on the potentiometer's end would be smaller than that on the screw's head. In order to ensure that the collar fit snugly around the potentiometer, a #4-40 set screw was used to tighten the collar.

The bracket used to restrict the motion of the potentiometer's housing had to be 'Z-shaped'. The lower horizontal plate had to be screwed onto the back of the hip box while the upper horizontal plate would fit just around the threaded portion (thread size ¼-32) of the potentiometer's housing. The nut supplied with the potentiometer would keep the bracket in place. Spacers were used between the lower horizontal plate and the hip box to account for the inaccuracy in determining the distance of the potentiometer's housing from the hip box and to ensure that the bracket was kept horizontal. The entire potentiometer and bracket design is depicted in Figure 9.

A hole was drilled through the hip box to allow the wires from the potentiometer's leads to be connected to the servo motor and microcontroller.

Should the robot fall on its back, a cap was used to protect the potentiometer from being damaged. A non-invasive cap is made out of Tupperware was used and was attached to the back of the left hip box by Velcro. To allow for visual indication, a long piece of heat shrink was attached to the set screw on the potentiometer's shaft collar. Since the shaft collar turned with the potentiometer, the position of the heat shrink gave an indication of the heading of the robot. Figure 10 shows the cap and heat shrink attached to the new steering system.

Testing on a similar servo motor was carried out to ensure that the Vishay Spectrol

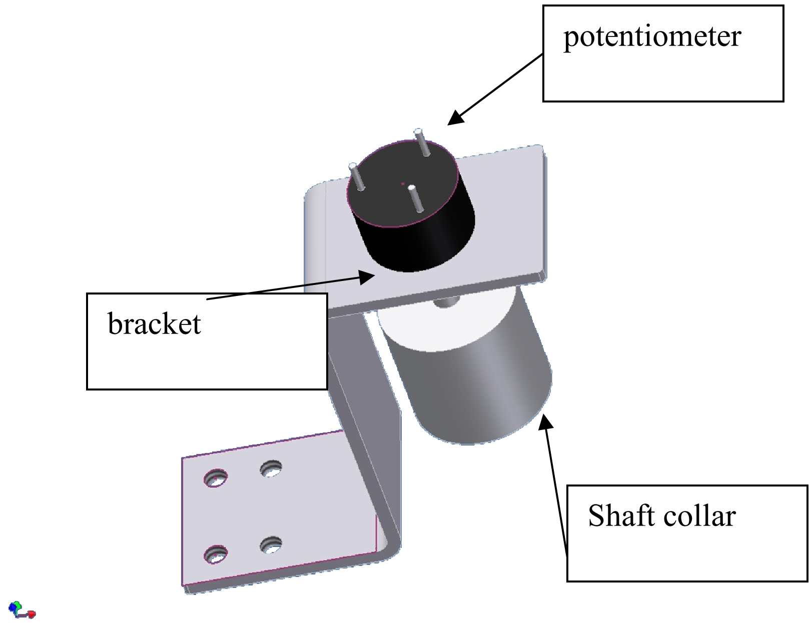


Figure 9: Potentiometer, shaft collar and bracket design

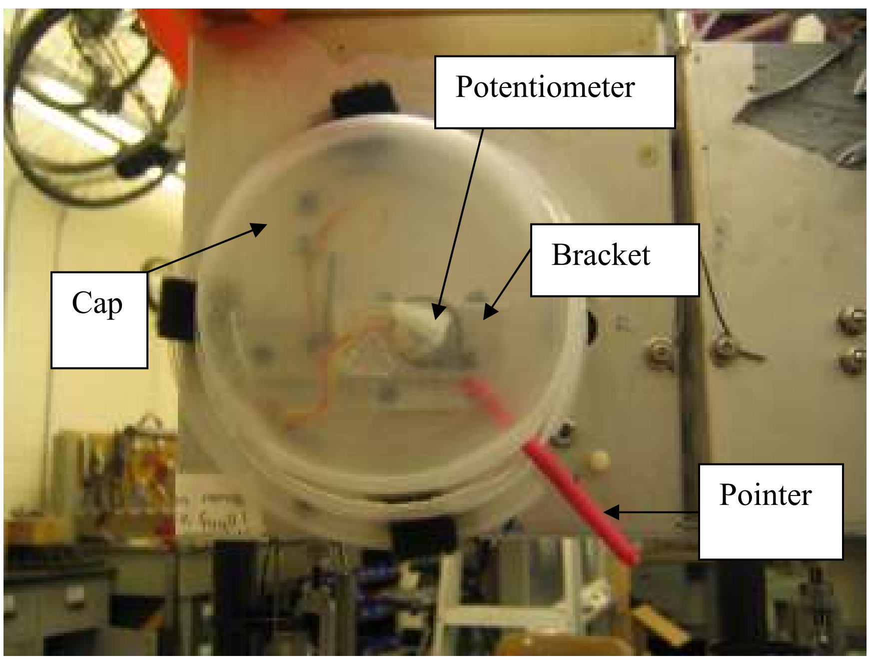


Figure 10: Cap and pointer attached to steering system.

3.3 Analysis

Testing on a similar servo motor was carried out to ensure that the Vishay Spectrol Model 140 Bushing Mount potentiometers in the lab were compatible with the servo motor's electronics.

The variable resistor in the servo motor was removed and the connection between the motor and its circuit board was also removed. The 3 leads from the potentiometer were soldered to the 3 corresponding positions on the board. The lead labeled 2 in the center of the potentiometer's housing was connected to the center pin of the board. The other 2 leads were arbitrarily soldered to the other 2 pins. The electrical board was then soldered back to the motor. Figure 11 shows the connections of the potentiometer to the board and the board to the motor. This motor is the actual motor used in the robot.

The servo motor was then gripped in a vice and a Labview program was written to supply varying voltage signals to the motor. The potentiometer was affixed to the rotating arm of the servo motor through the use of duct tape.

Firstly, the potentiometer was found to be compatible when it responded to the change in voltage of the Labview program. By changing the voltage signal, the servo rotated in a different direction.

Secondly, to ensure that the wiring between the potentiometer and electrical board was correct, the voltage signal was suddenly decreased or increased. A change in direction of rotation of the servo arm motor would indicate that there was no error in the wiring. When an error in wiring was discovered, instead of swapping the outer 2 wires from the potentiometer to the electrical board, the connection between the electrical board and motor was swapped instead. The latter swap was done due to the easier soldering work involved but achieved the same effect as the former. The swap in wirings was needed to obtain the right phase between the actuator (potentiometer) and feedback device (RC servo motor) for the closed-loop feedback to work accurately.

The results of the Labview testing showed that the connections between the board and motor had to be crossed. The left wire should be connected to the right lead of the motor and vice-versa. On the potentiometer, lead 1 (red wire) would be connected to the bottom pin on the board, lead 2 (orange wire) would be connected to the center pin and lead 3 (yellow wire) to the top pin.

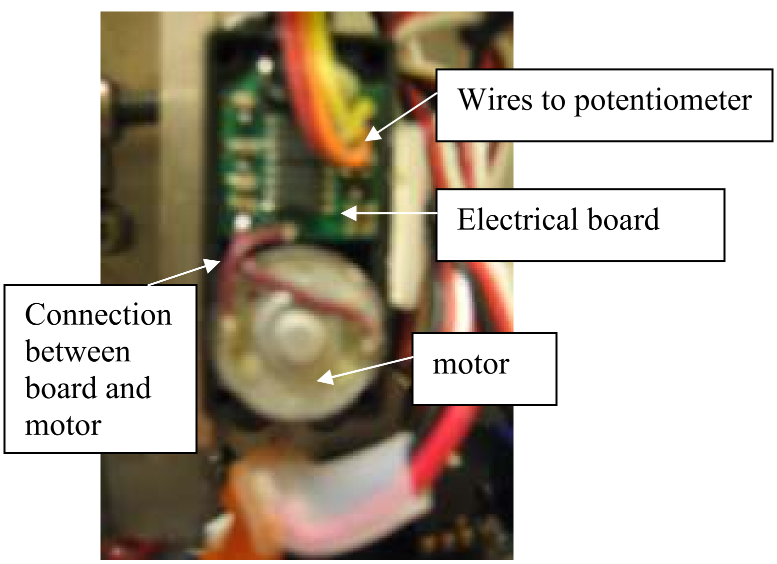


Figure 11: Connections from potentiometer to circuit board and from circuit board to motor

4. FABRICATION

4.1 Drawings

Once the bracket and shaft collar design, including the dimensions of each part, was finalized, CAD drawings were created. Critical dimensions were labeled along with notes regarding thread sizes and hole diameters. Tolerances were not included in the drawings as the design did not have to be that accurate for it to work. Caution taken during machining was deemed sufficient for a successful design. Since the new steering system was needed urgently in order to improve the general reliability of the robot, severe time-constraint was faced. Thus, adhering to strict tolerances would severely increase the time needed to complete the product. The machining drawings are included in Appendix A.

4.2 Parts

Several mechanical and electrical stock parts had to be ordered from vendors during the course of the project. These parts were inexpensive and were readily available. Furthermore, some of these parts could not be made or machined using the equipment available in the lab. This was especially true for the electrical components that were needed to complete the design. A complete list of the parts ordered is included in Appendix B.

4.3 Materials

Most raw materials were taken from the machine shop. Since the strength of the materials were not important, aluminum was chosen as it was light. The stock was chosen based on the desired dimensions of the part that was being machined. To ease machining and reduce machining time, the stock used had dimensions as close to the desired dimensions as possible.

4.4 Machining

All parts were machined using the conventional mill and lathes found in the Kimball Hall Machine Shop. No specific steps were planned for machining since the level of machining required was very basic. Parts that were machined on the mill only required a standard vice to grip the parts. No rotary table was needed. On the lathe, the parts were all held by the jaw chuck. Other operations included horizontal linear cutting on the horizontal band saw and shear, external threading using a die set and internal threading using a tap. The size of the body drills and tap drills for each specific threaded hole size was obtained from a tap and die chart. The sheet metal was bent by gripping it in a vice and bending it down manually using a mallet.

4.5 Assembly (remote control picture)

Once all the parts had been manufactured, they were put together on the robot. As expected, assembly was not overly complicated. However, the wiring of the potentiometer to the servo motor took longer than expected. Lack of experience in soldering resulted in several bad connections and short circuits. Searching for the source of the short took up to twenty-four hours. Another problem encountered while assembling the new steering system to the current one on the robot was that the current system was not designed to have a load attached on the back of the robot. The added load and continuous turning of the potentiometer shaft and screw head to which it was attached to resulted in the screw coming lose within the gear extension hub. (Refer to Figure 5) The whole system had to be removed in order to tighten the screw. This occurred numerous times throughout the testing process.

In the current steering system, steering would be carried out by first turning on the robot's main power and steering system. The handheld steering controller would then be turned on. Figure 12 shows the handheld steering controller. To begin steering, the user would have to hold the left bar in its up position and move the right bar at the same time. Moving the right bar left will cause the steering system to rotate clockwise and vice-versa. If the steering system starts rotating while the left bar is held upwards, the user would have to adjust the offset tab to center the system manually. [1, 21]

In the new system, the steering system would be powered up using the same procedure as the old system. Steering would also be carried out by first holding the left bar up. The difference between the two systems lies in the ease of steering the robot. Moving the right bar to the left will now cause the robot to turn to its right (left foot moves up more than the right foot) while moving the bar to the right will turn the robot to is left (the left foot moves down more than the right foot), instead of having to visually inspect the foot level each time the controller is moved.

Another significant difference lies in the function of the left control bar. By holding up the left control bar without moving the right, the robot would automatically adjust to its neutral position. Both feet would be at the same angle relative to the leg and the robot would ideally walk in a straight path.

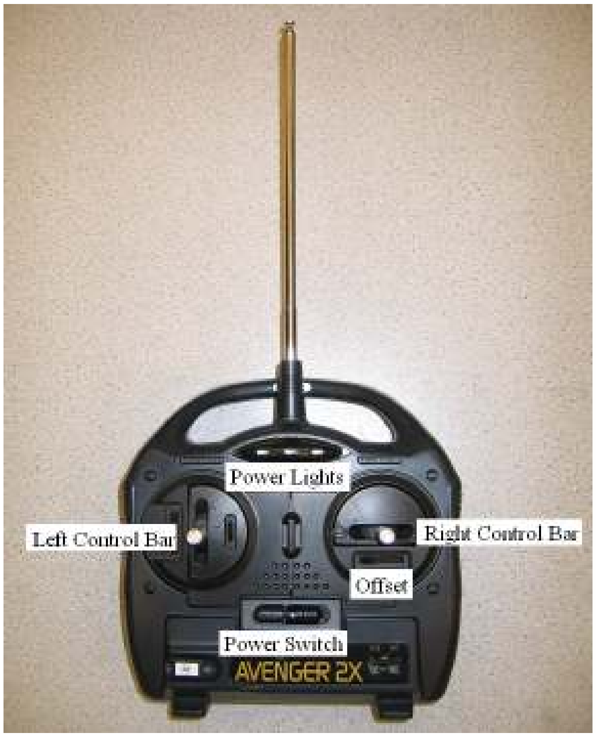


Figure 12: Steering handheld control system. [1,21]

5. TESTING

Testing of the new steering system was first carried out in the hallway outside the lab. This test was done just to ensure that the robot would respond in the right manner and turn in the direction it was supposed to. After these tests proved successful, the robot was taken to the indoor track at Barton Hall. Here it was made to go round the track which had a turning radius of 25m. A test was also conducted on the indoor basketball courts at Helen Newman. The tests were carried out on the following categories:

- Changes in the parameters of the robot, especially on the hold feet down angle – the angle at which the feet strike the ground relative to the legs.

- Floor sensitivity – The different surfaces on which the robot was tested (hallway, indoor track, indoor basketball court) affected the success of the steering system greatly.

5.1 Mechanical Failure

As mentioned in Section 4.5, the old steering system was not designed to have a load on the back of the left hip box. The screw holding the gear extension hub and bearings to the box began to unwind and the potentiometer would no longer be accurate. It would not be able to send the right feedback to the computer and the steering system would fail. Continuous tightening of this screw eventually caused it to shear and break within the gear extension hub itself before testing in Barton Hall could take place. Thus, more modifications to the old steering system had to take place.

A side view of the old steering system is shown below in Figure 13.

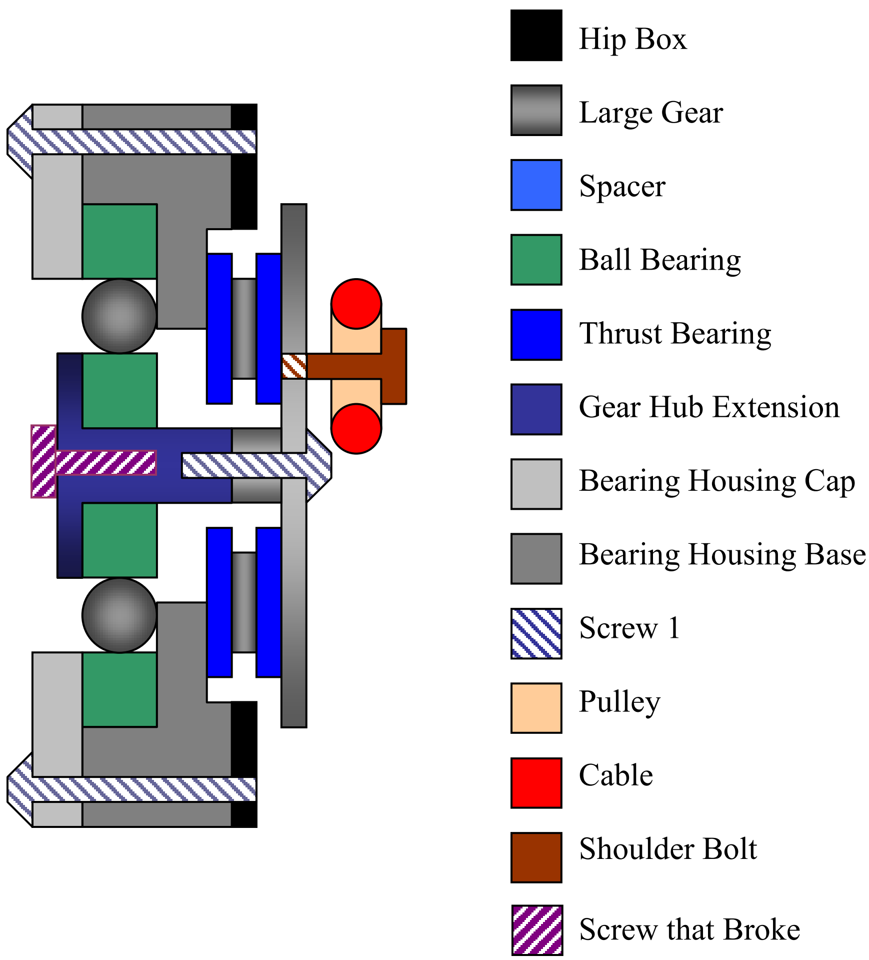


Figure 13: Side view of old steering system. [1, 15].

To prevent a similar occurrence from taking place, the gear hub extension, screw 1 and the broken screw were removed from the design completely. A new system was designed with the parts that were mentioned above incorporated into a single new bolt that was threaded externally. Figure 14 shows an isometric view of the new gear hub extension.

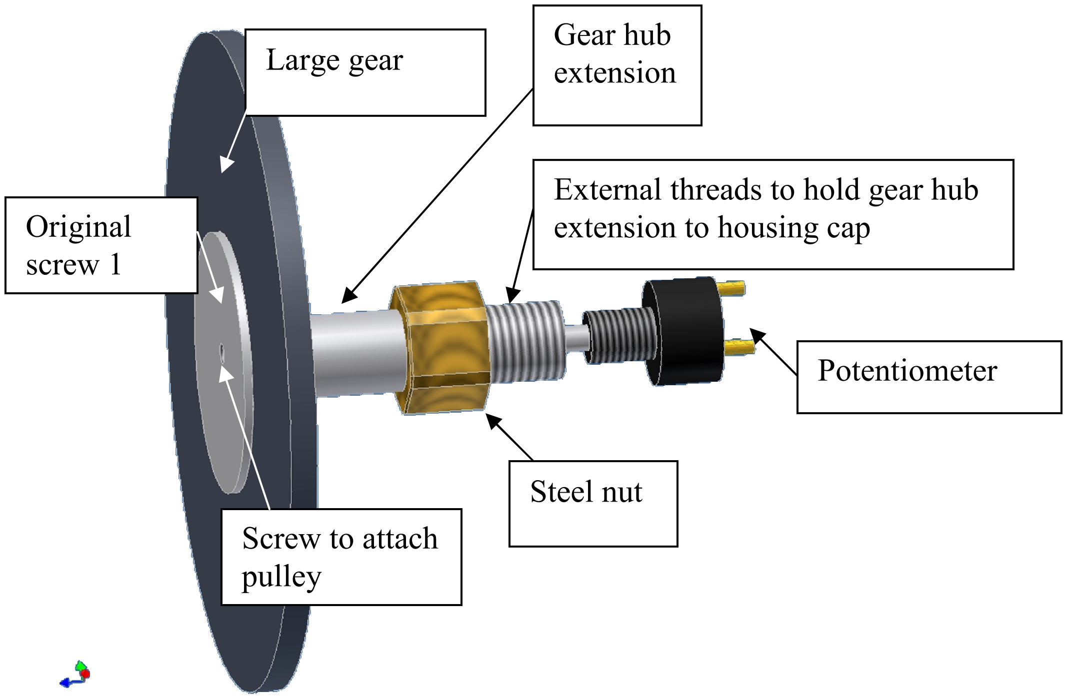


Figure 14: Isometric View of new gear hub extension.

The new gear hub extension now only consisted of a single rod to hold the gear to the back of the hip box and to hold the various bearings in the right position. A hole was also drilled into the end of the gear extension hub for the potentiometer's shaft. A steel nut with nylon inserts prevented the system from coming apart and loosening as the shaft turned. This new design eliminated the need for the shaft collar that was used previously and also eliminated the possibility of the system coming apart as with the old system. The bracket designed previously could still be implemented to prevent rotational motion of the potentiometer's housing. Drawings for the new gear hub extension are included in Appendix A.

5.2 Trim Pots

Testing of the new steering system was carried out in Barton Hall. Preliminary tests showed that the range of motion provided by the potentiometer was insufficient for the robot to complete the 25m radius turn on the Barton Hall indoor track. Trimming potentiometers were included into the steering system in order to increase the range of motion of the potentiometer. Since a voltage would be applied across the ends of the trim pots, the resulting maximum voltage range applied across the ends of the potentiometer to be less than the previous 3V. As the potentiometer's resistance is proportional to its voltage across its ends, the potentiometer can now increase its resistance and thus range of angular motion without reaching its 3V maximum range. Thus, the range of motion of the large steering gear is also increased.

Two Vishay Spectrol model 43, 6-1-0 rectangular trim pots were attached to the right side wall of the left hip box. 1 trim pot controlled the maximum negative displacement angle (anti-clockwise) of the large gear while the other controlled the maximum positive displacement angle (clockwise) of the large gear. Such increase in motion allowed the robot to have a smaller left and right turning radius respectively. The trim pots are show in Figure 15.

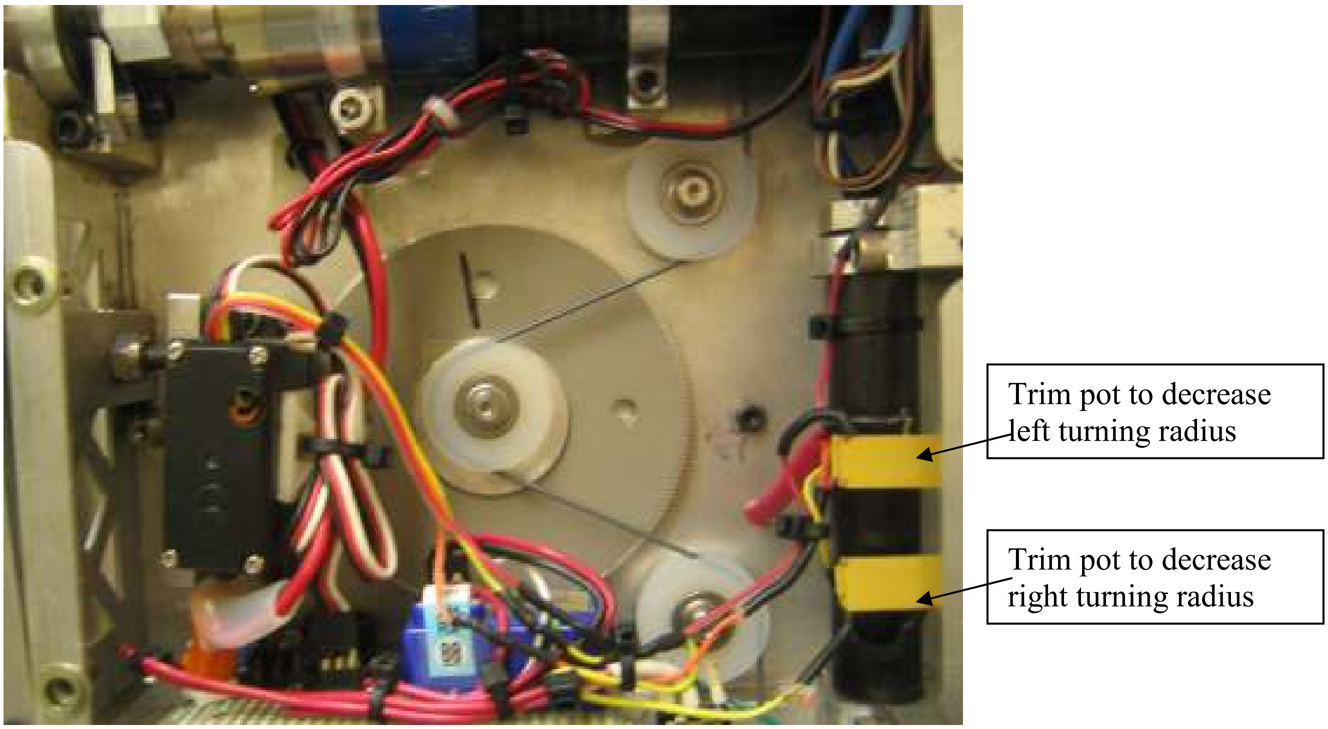


Figure 15: Trim pots attached to servo motor in left hip box.

The range of motion was adjusted by turning the screw inside the trim pots. 1 lead on the trim pot was connected to the potentiometer, the other to the circuit board in the motor. Each trim pot was connected to a different pin on the circuit board. The trim pots were then adjusted till the range of motion of the gear was -90° to +90°. This was the maximum range before the robot became unstable.

5.3 Parameters

From tests done on the previous steering system last semester, it was found that the parameter which most affected the sensitivity of the steering was the hold feet down angle. This parameter referred to the angle at which the robot's feet was held relative to its legs when it made contact with the floor. It was decided to carry on testing this parameter in order to make the robot more sensitive to this new steering system. The hold feet down angle was first made more positive (the feet is held higher up with respect to the horizontal) and the effect on the robot was observed. Next the angle was made negative and the effects were once again taken note of. However, the tests done on the robot was highly inconclusive. When a new set of parameters were input into the robot, the former value of the hold feet down angle would no longer have the same effect on the robot. More tests would have to be done before the right value of the hold feet down angle is chosen to make the steering system effective. (See Section 7.4 for future tests to be done on the robot.)

5.4 Floor Sensitivity

The surface of the ground on which the robot was walking also influenced the success of the steering system. The robot was found to be very responsive to the steering system on the lab's floor. It had a turning radius of less than the required 25m without utilizing the maximum displacement angle of the steering gear. In Barton Hall, however, the robot could barely complete the 25m turn. Testing carried out at Helen Newman found the steering to be ineffective. The robot did not turn at all on the smooth surfaces of the indoor basketball courts.

Without more tests, nothing conclusive can be said about the effect of floor surface on the steering system. However, one hypothesis that can be drawn is that friction affects the turning radius of the robot. A smooth surface with a low coefficient of friction makes the steering system completely useless while very rough surfaces such as the indoor track at Barton Hall, does not make the system completely successful either. A moderate coefficient of friction is thus the ideal surface for the robot to make sharp turns. This sensitivity to friction might be due to the drag on the feet. With 1 foot held at a lower angle than the other, this 1st foot would experience more drag with the ground and thus would move at a slower speed, causing the robot to turn to the side of the lower foot. Thus some friction is needed in order to cause steering while a large coefficient of friction will result in the difference in frictional force acting on the two feet to be negligible. As with the parameters above, more tests would have to be carried out to determine the cause of the sensitivity to different surfaces.

5.5 Weight

It was also hypothesized that a new steering system could be added onto the robot where the use of mass distribution could aid the current system. By making one side of the robot relatively heavier than the other, the robot would turn in the direction of the heavier side. This was due to the added mass, causing the robot's leg to move slower than the other. The added weight also resulted in an addition momentum about the robots center of mass, which helped rotate the robot about the vertical axis.

Tests were also carried out with weights attached on the leg of the robot, near the feet. With a 1kg weight attached to one leg, the robot would turn sharply in the direction where the weight was attached as hypothesized.

Though the results of the weight test showed that the hypothesis was correct, after considering designs on how to implement the weights on the leg, it was realized that this concept cannot be applied to the steering system. For the robot to walk in a straight path, the weight would have to move from the bottom of the leg to the top to reduce the momentum about the robot's center of mass. Motors would have to be used to move the weights to various positions along the leg. Such a system would be overly complicated, require much additional power and interfere with the current system already implemented on the robot.

6. EVALUATION

The new steering system could then be compared to the specifications to see how well it meets the needs. Other aspects such as safety and aesthetics could also be compared.

6.1 Meeting Specifications

Specification	Target Value	Actual Value
Max power drawn	< 2W	2W
Voltage drawn	3V	3V
Mass	<50g	16.7g
Dimensions	<6.5" x 4.5" x 2"	3.5" x 1.3" x 2.5"
Cost	< $100	$64.85
Fabrication Time	< 3 weeks	≈ 3 weeks

Table 2: Target values and actual values of the specifications

As seen from the Table 2, the actual values have met the target value. This was not surprising since the design that best fits the specifications was chosen. The fabrication time could have been reduced to 2 weeks had the screw not sheared. The fabrication of the new gear extension hub took about 1 week to complete.

6.2 Safety

There is little danger associated with this steering system. The system is completely enclosed within the left hip box or by the steering cap. However, the steering cap may become displaced due to the non-permanent method of attaching it to the hip box via Velcro. Should the cap become displaced, the wires would be exposed. Any break in the insulation could pose a danger to the user. However, the current flowing through the wires is too small to produce any permanent damage. Hence the system is completely safe to use.

6.3 Aesthetics

The use of bright colors for wire insulation and the visual pointer is an attempt to increase the attractiveness of the steering system. Additional wires were cable tied to permanent fixtures such as the hip box or bracket. The attractiveness of the system could be improved by using a more attractive steering cap that is colored. However, the visual pointer would have to protrude out of the cap in order to provide any form of visual aid to the operator. Since attractiveness was not a major need of the steering system, the design was not chosen based on its aesthetics and any major attempt to increase its aesthetics would have been a waste of resources and time.

6.3 Reliability

With the new gear hub extension installed, no part of the system is subjected to any form of significant stresses. Hence the system should no longer fail mechanically. The part that is most susceptible to failure would be the potentiometer, which has a loading life of 900h. This will not be an issue for the robot, which will not be walking for 900h.

After several rounds of testing, it was found that the 2 outer feet on the robot constantly became misaligned. While set to walking in a straight line, the outer feet would not be held at the same angle. In order to realign the feet, the cables attached to one of the feet would have to be unwound and the pulley at the base of the feet would have to be turned such that when the cable was rewound, the 2 feet would be held back at the same angle. This process was unnecessarily complicated and tedious. To increase the reliability of the system, a pulley fixture was designed that would be attached to the leg near the feet. Figure 16 shows the pulley fixture attached to the leg while Figure 17 and Figure 18 show a close-up of the pulley fixture.

The cable would slide along the pulley and as the feet moved up and down, the pulley would rotate, aiding the motion of the cables. The pulley could also move horizontally along the bracket. By adjusting the position of the pulley in the bracket, the degree to which the cable is displaced from its vertical position changes. The pulley is currently set such that when the 2 feet are aligned, it is at its outermost position. Pushing the pulley in will hold the feet up more.

Plastic was chosen as the material to make the fixture as it had to be light. Polycarbonate was chosen as it was strong enough and yet had a higher coefficient of friction than Delrin. This would prevent the fixture from slipping down the leg of the pulley. Both the polycarbonate and pulley were ordered from McMaster Carr and machining of the bracket was done on both the lathe and mill. Drawings of the pulley fixture are included in Appendix A.

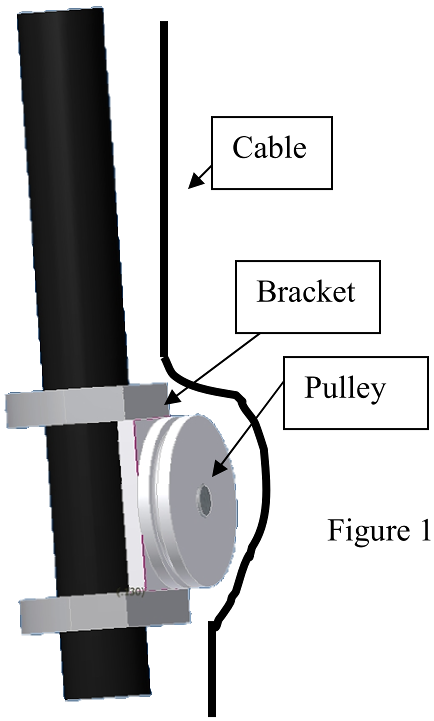


Figure 16: Pulley fixture attached to leg

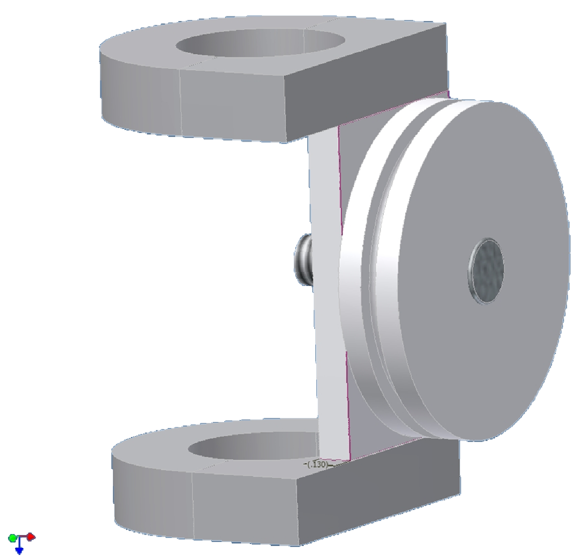


Figure 17: Isometric view of pulley fixture

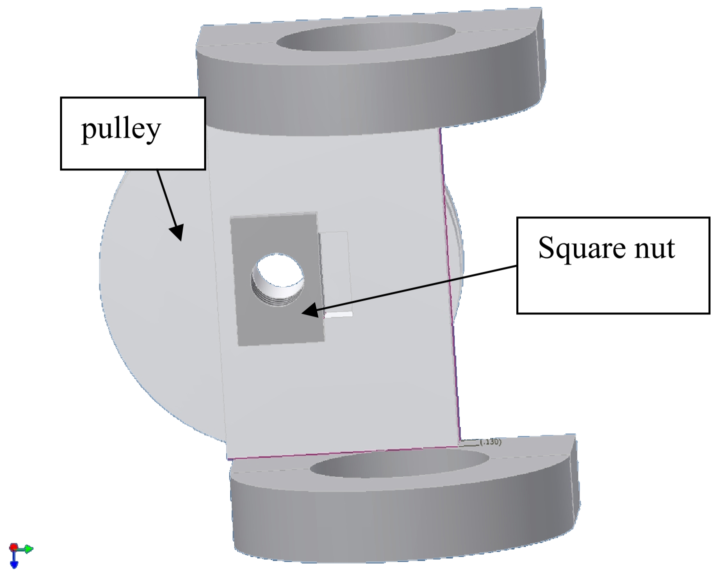


Figure 18: Back view of pulley fixture

7. DISSCUSSION

The steering system met most of the objectives listed in Section 2.2. It can now provide feedback to the computer. Unfortunately, the steering system is still fairly unreliable in terms of its consistency. Depending on various factors, such as the speed of the robot's walk and the parameters input into the robot, the steering system may or may not allow the robot to complete the turn on Barton's indoor track. Hence the steering system can only be deemed successful to a certain degree. More improvements could certainly be made to the system and are listed below.

7.1 Conceptual Design

The decision to go with the potentiometer has been proven wise. The inexpensiveness and ease of fabrication has been seen by the short time and small amounts of money that were used to build the system. The potentiometer did provide feedback to the system and allowed for automatic correction to the neutral position (straight-ahead path) of the robot. However, there was much noise in the signal coming from the potentiometer. A programmable angular sensor might have been able to eliminate such noise but the drawbacks of such a sensor certainly make it an unattractive choice. Other electrical sensors which do not rely on external magnetic fields such as lasers might be worth considering.

7.2 Detailed Design

The use of the pulley-fixture to increase the reliability of the steering system is only a short-term remedy. Detailed observations and more testing would have to be done to determine the cause of the misalignment and a long-term solution would have to be developed. This might involve redesigning of the cable system to prevent any slack from developing. Also, the pulley is set such that at is outermost position, the feet are properly aligned. The pulley can only move in one direction – in. This only allows one direction of motion for the feet. Should the left foot be at a higher angle than the right, the pulley fixture is unable to bring it down. Thus a larger bracket might have to be developed, with the pulley set in the middle while the 2 feet are properly aligned.

7.3 Fabrication

Before a revision to the pulley system can be made (see Section 7.2), more stock would have be ordered from McMaster Carr. For the current pulley fixture, the rectangular brackets were machined out of a cylindrical piece of polycarbonate to reduce costs. Much time was spent reducing the circular cross section to a rectangle and machining the sides such that they are parallel. Inaccuracies resulted in the rectangular brackets not being exactly rectangular and not fitting perfectly well with the circular brackets. This might result in slippage after several rounds of testing. A rectangular piece of polycarbonate would eliminate such errors and increase the reliability of the fixture.

7.4 Testing

The testing mentioned in Section 5 did not yield satisfactory results. As a result, more tests would have to be carried out in order to determine the right set of parameters and displacement angle of the steering gear in order for the robot to complete the 25m turn in Barton Hall. This would involve a systematic approach to testing whereby a set of parameters simulating an added weight on the front of the robot would be input into the robot. Once this set of parameters have been stabilized, the parameters that affect the steering sensitivity such as the hold feet down angle would then be adjusted to decrease the turning radius of the robot until it completes the turn every single time.

The effect of different floor surfaces on the steering system would have to be determined. Tests could be carried out where the robot walks on surfaces of different coefficients of friction ranging from very smooth surfaces such as glass to very rough surfaces such as tarmac. The hypothesis that a moderate coefficient of friction is needed for the steering to work effectively can then be analyzed.

8. CONCLUSION

The modifications to the old steering system implemented on the robot have provided important insight into steering a 4-legged robot. Although several suggestions to improving the reliability of the steering system has been suggested above, the modifications that can be done on the robot without severely changing any current systems has almost been exhausted. This suggests that the idea behind this mode of steering does not provide a turning radius on the robot that is smaller than the 25m turning radius in Barton Hall. Thus in building future 4-legged biped robots, one can look to other forms of steering instead of relying on the difference in contact area of the feet and the ground.

9. REFERENCES

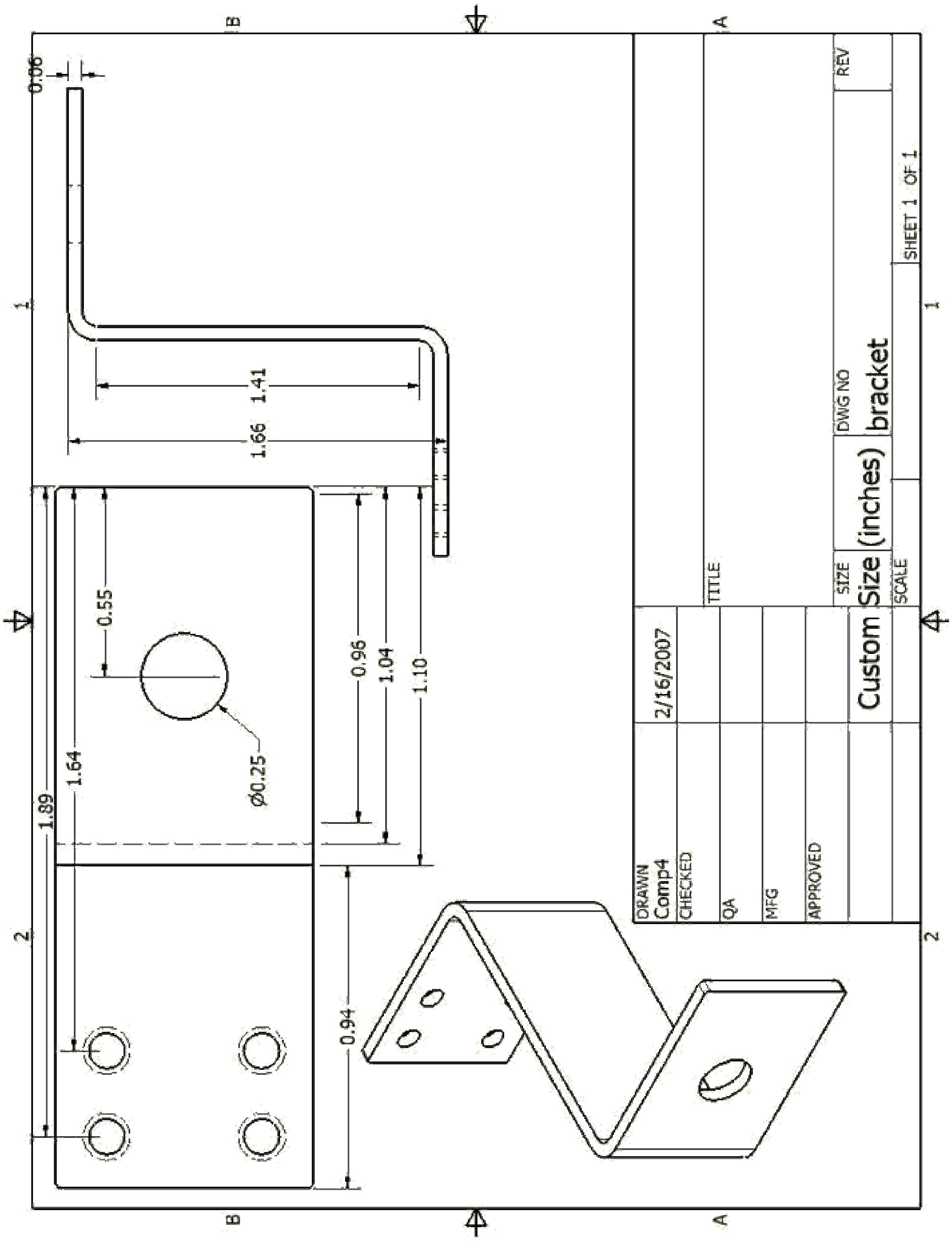
[1] M. Berry, *Steering System Design for Four-Legged Biped*, M&AE 429, Senior Design Report, Fall 2006.

[2] Honeywell Sensor Products, *Linear / Angular / Rotary/ Displacement Sensors/HMC1501 / HMC1512*. Available online at: http://www.ssec.honeywell.com/magnetic/datasheets/hmc1501-1512.pdf

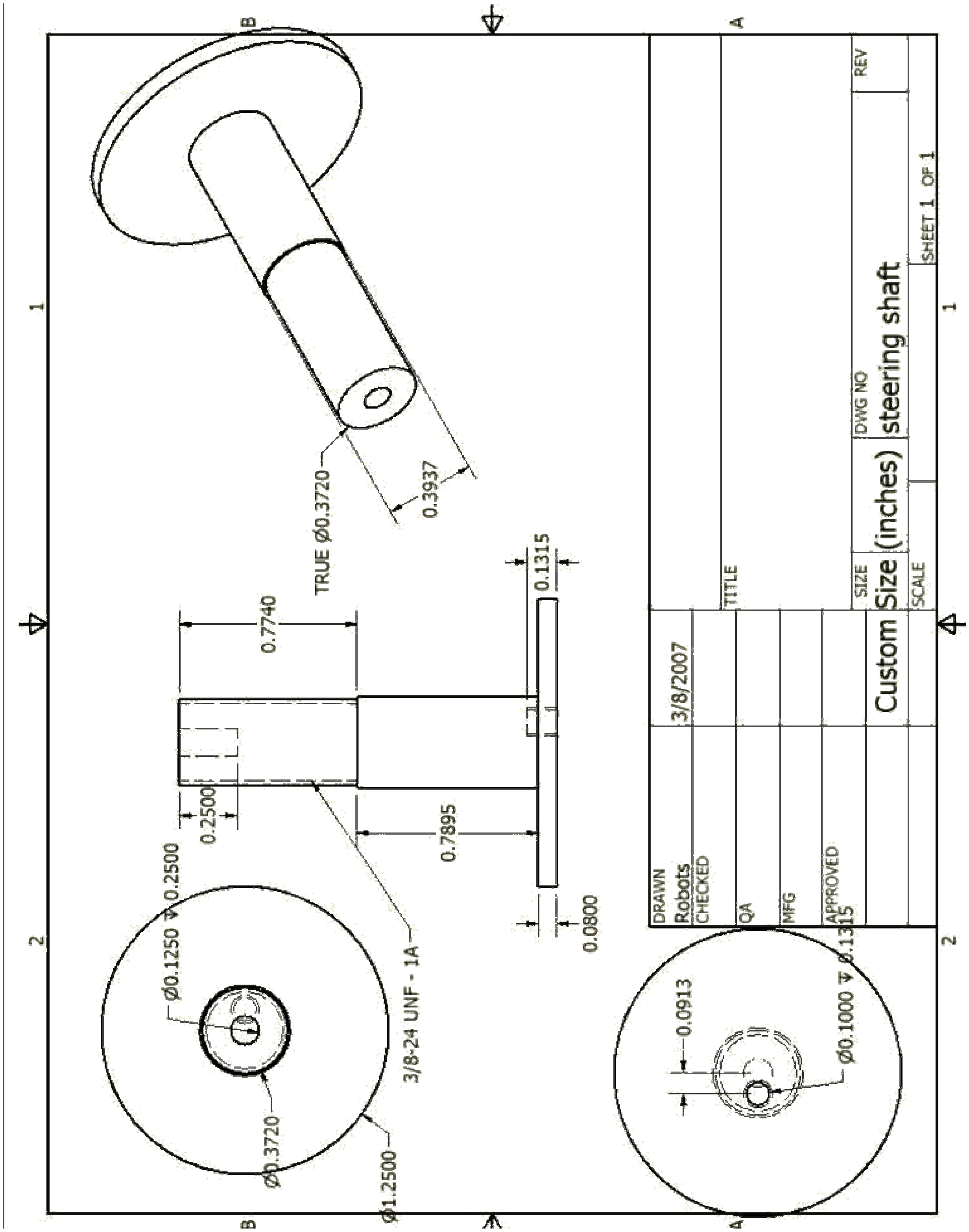
[3] NXP, *Product Description, KMA200;Programmable Angle Sensor*. Available online at: http://www.nxp.com/pip/KMA200_6.html

APPENDIX A

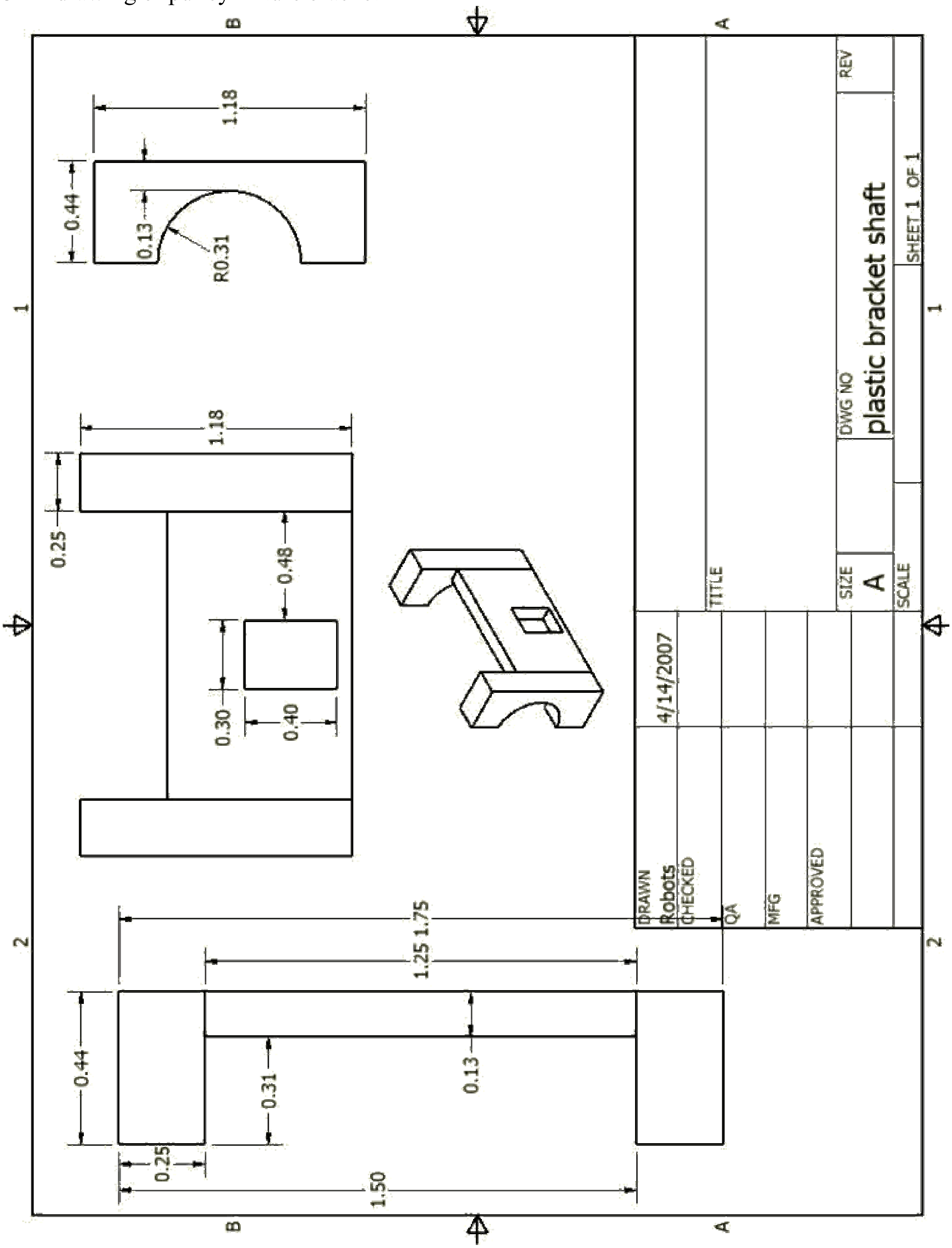
CAD drawing of bracket used to hold potentiometer's housing stationary



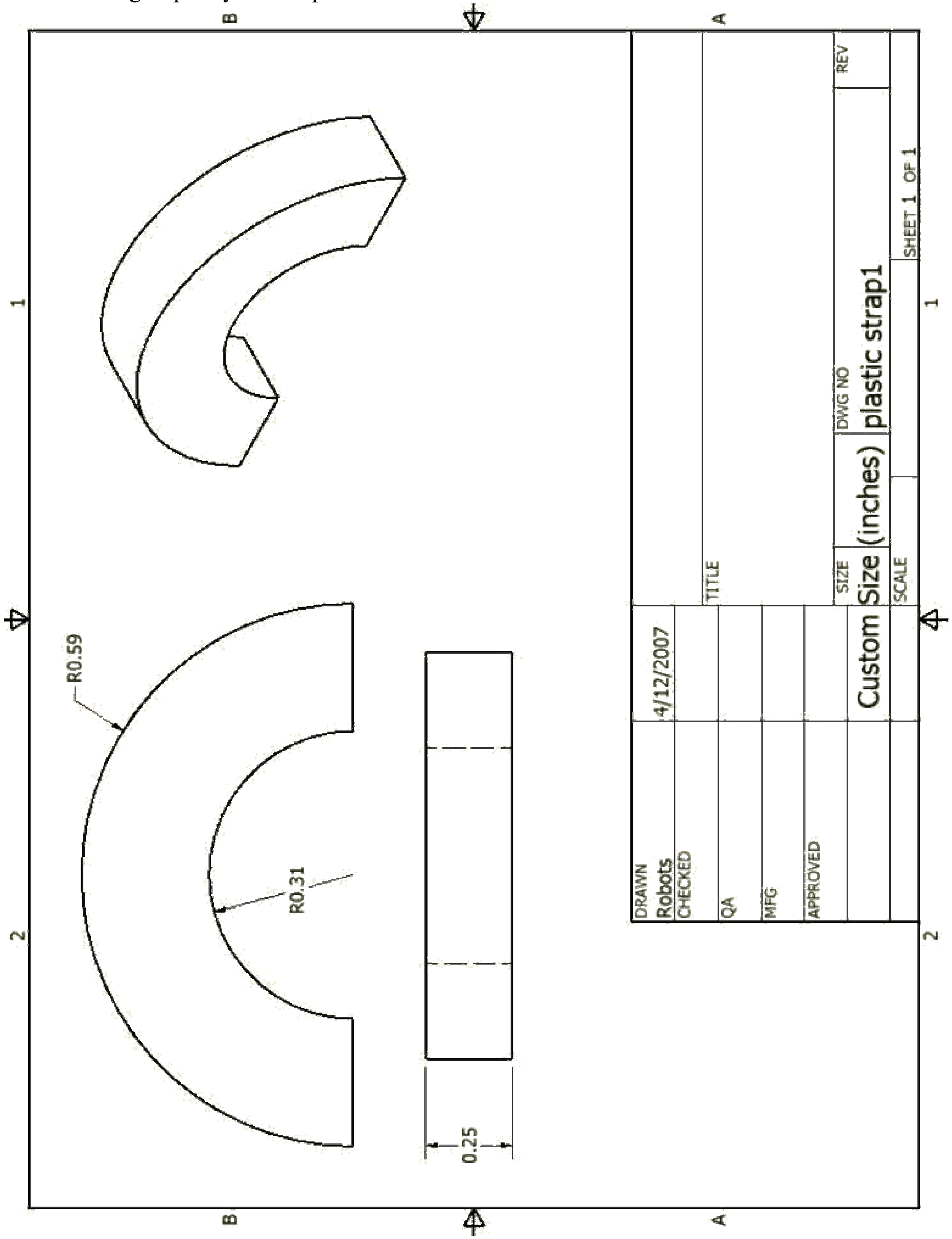
CAD drawing of gear extension hub



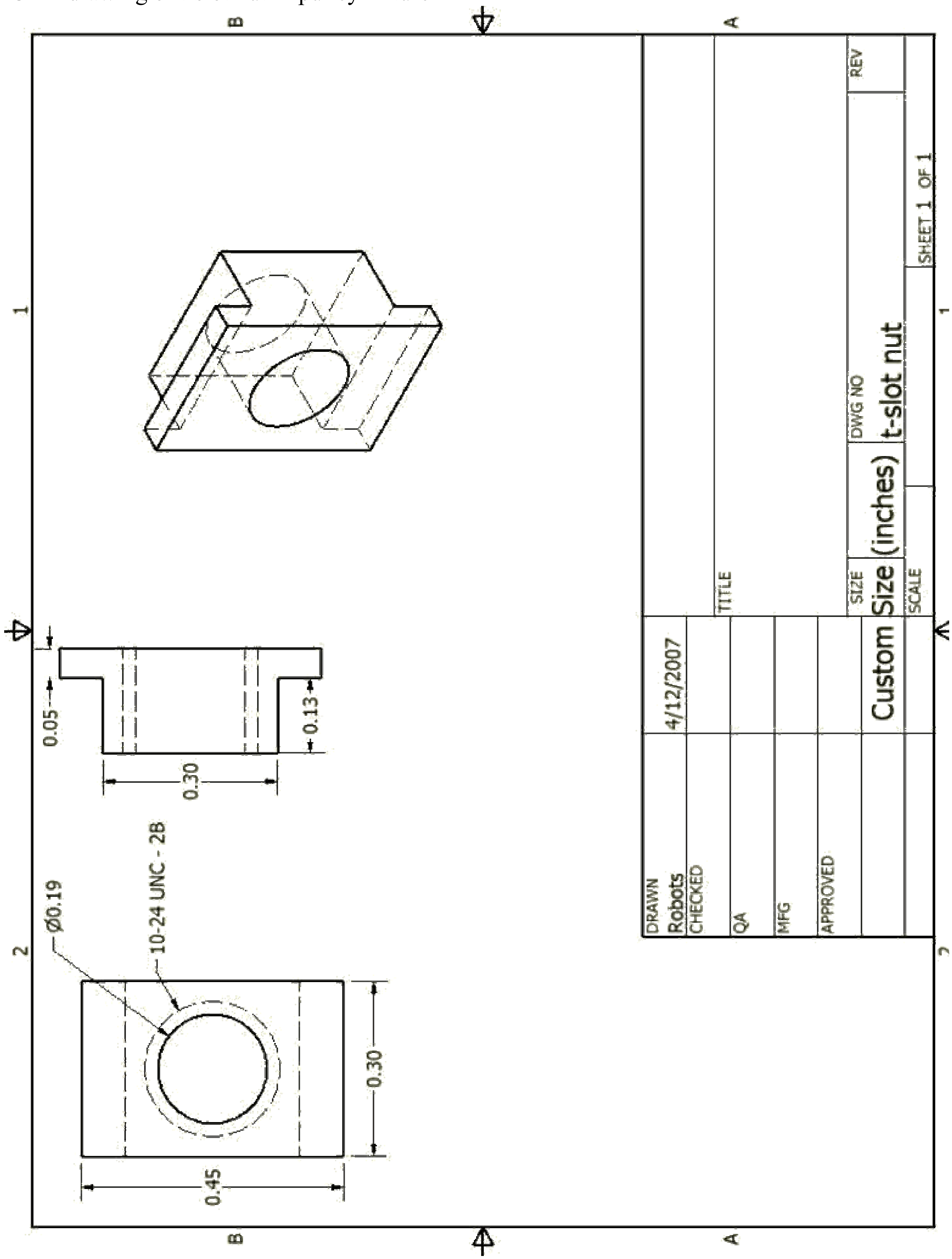
CAD drawing of pulley fixture bracket



CAD drawing of pulley fixture plastic bracket 2



CAD drawing of t-slot nut in pulley fixture



Appendix B

The following stock parts were found in the laboratory:

- Type: Model 140 Bushing Mount
- Manufacturer: Vishay Spectrol
- Total resistance: 50Ω to 20K Ω
- Power rating: 2W at 40°C to 0 at +125°C

- Type: 6-1-0 ¾" Trimming Potentiometers. Model 43
- Manufacturer: Vishay Spectrol
- Resistance Tolerance: 10%
- Power rating: 0.75W at 70°C
- Operating Temperature: -55°C to +125°C

- Type: TowerPro MG995
- Manufacturer: TowerPro
- Weight: 55.0 g
- Stall Torque: 10Kg/cm
- Operating Voltage: +4.8V-7.2V

The following parts were ordered from McMaster Carr:

- Type: Pulley for Wire Rope
- Manufacturer: McMaster Carr
- Rope Diameter: 1/16"
- Outer Diameter: 1 ¼"
- Work Load Limit: 90lbs

- Type: Black Polycarbonate Rod
- Manufacturer: McMaster Carr
- Diameter: 1"
- Length: 1'