Simon Fraser University

School of Engineering Science

Micro Air Hockey Robot

ENSC 386, Introduction to Mechanical Design

PROJECT #2

April 25, 2016

Submitted By:

Group 1

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Introduction

The objective of this project was to design and build a micro air hockey robot to compete in a competition. Due to the nature of the competition, both the required shooting and catching mechanisms needed to be mounted on a moveable platform. As such, we spent our initial few meetings discussing various designs for each feature and their respective merits. We ended up coming up with two overall completely different solutions for the hitting and catching mechanism, and three different configurations for the platform design. However, due the rationale discussed in Section 1.0. Only the chosen designs for each category were implemented and constructed together, as seen in *Figure 1* below.

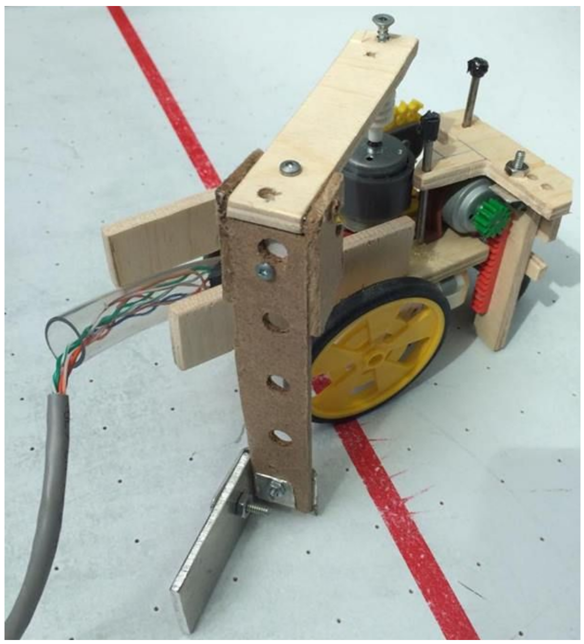

Figure 1: Final Design of the Hockey Robot

By using the dimensional measurements generated during the construction of the robot. Both a Solidworks model was constructed, followed by dynamic puck impact analysis.

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1.0 Design Synthesis

1.1 Mobility

For the mobile platform, we went through three major development stages, with each subsequent design trying to eliminate the failings of the previous design, for the implementation of the chassis.

1.1a Four Wheels

The first design we considered was the classic four wheel ‘two’ axle design utilized by most vehicles. The reason that we decided to initially thought of this design was that we were all familiar with how the robot would operate and maneuver. Additionally, by using a well understood and relatively simply constructed design, valuable time could have been saved during the research and development phase of this project. Furthermore, by using two sets of wheels and axis (technically we only had one axle since the two drive wheels were independently powered), the platform would have an instinct stability associated with having four points of contact. However, this design had three major drawbacks: the platform was no longer parallel with the surface, i.e. the main platform was tilted due the radius discrepancy between the two sets of wheels; the proposed (and constructed) guide wheel set prevented sufficient rotation about the z-axis due to collisions with the rest of the chassis, ultimately resulting in poor turning ability; and finally, the proposed design would far exceed the maximum dimensions of 10x10 centimeter in the x-y plane (assuming the surface on which the chassis rolls upon in the x-y plane).

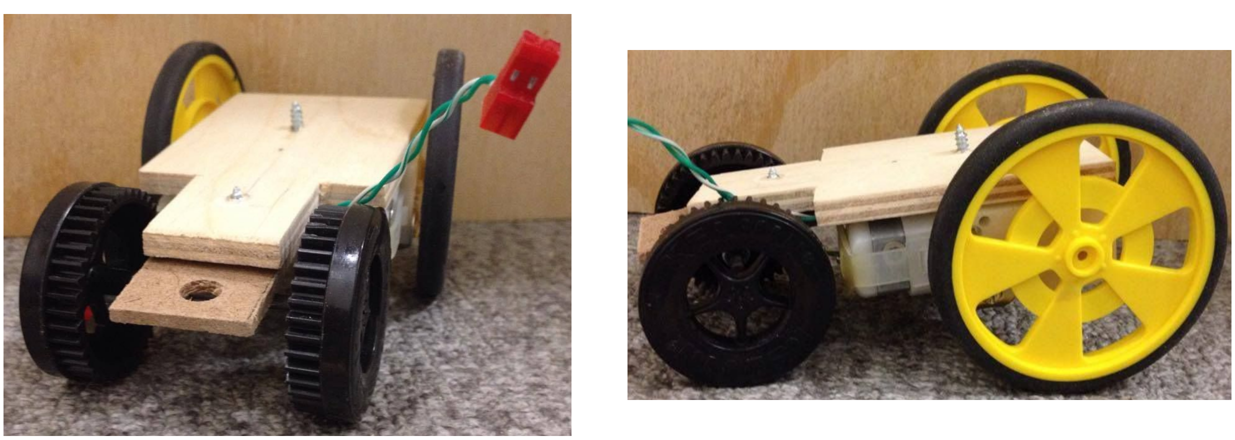

Figure 1: Four Wheels Approach

1.1b Tricycle

After analysing the failings of the previous design, we realized the major reason those failure existed wasn't due to the main component of the design (i.e. the use of two guide wheels connected by a shared axel) but rather do with the dimensional proportions of the design. As such, design an alternative solution which tried to turn the previous weaknesses into strengths.

Thus, the 'Tricycle' was born as seen in *Figure 2*.

The reason we decided to explore the use of a tricycle based platform was that by using a single wheel mounted in the center of the rear section (assuming the two drive wheels represent the front of the chassis). The chassis would be able to turn on a single point, thus allowing far greater turning ability when compared to the previous design; while only sacrificing a moderate amount of stability due to absence of an additional guide wheel. However, due to the method of construction and the use of a machine screw as an axle, this design proved to be too unstable and unbalanced, due to the flimsy sheet metal utilized to create the upside-down U bracket. Additionally, the platform was not exactly levelled as required to give us the most flexibility in the design of the shooting and catching mechanism.

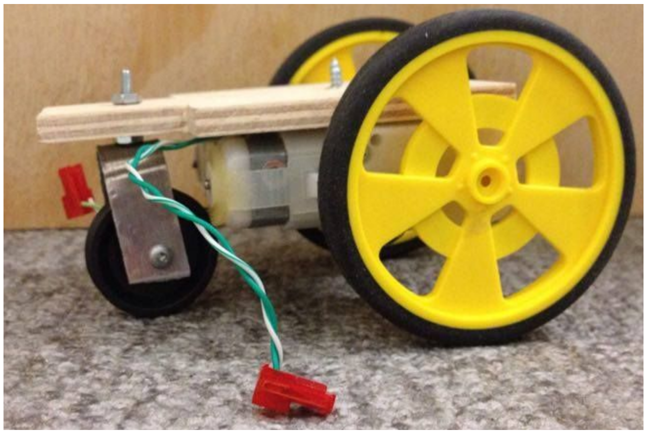

Figure 2: Tricycle Approach

1.1c Twin U-Bracket

The final design of the chassis, and the one ultimately used in the design, came about through a chance encounter with Mr. Houghton when I (Caelan) was trying to design a better U bracket for the previous design. Under the suggestion and guidance of Mr. Houghton, a more rigid U bracket was cut from a much larger piece of what looked to be a railing of sorts. Conveniently, this new U bracket had two perfectly lined holes along the edges allowing the use of wheel and axle set used in the first design. Thus, only a small ‘pivot’ hole was required to provide the desired z-axis rotation. Furthermore, by the use of lock nuts, it was possible to both fix the position of the U bracket on the machine screw (providing just enough space for relatively unhindered bracket rotation) and allow the fine tuning of where the rest of the platform meet the guide wheels’ z-axis shaft. Additionally, due the use of the short axle, the guide wheels were able to fit more snuggly underneath the chassis. Resulting in a closer adherence to the desired dimensional constraints. Thus, this design provided the best balance in terms stability and turning ability while shortening the axle position relative to the rest of the chassis. Figure 3 contains the completed robot but the U bracket and guide wheels can be seen in the lower left hand corner.

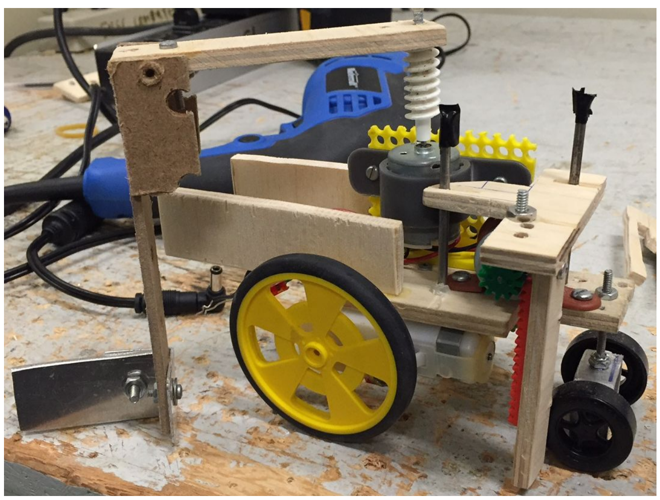

Figure 3: Twin U-Bracket

1.2 Hitting Mechanism

1.2a Baseball Pitching Machine Analogous (BPMA)

Our initial idea for shooting mechanism was inspired by a baseball pitching machine, see Figure 3. However, the two rotating wheels would be placed along the xy-plane, instead of the z-axis.

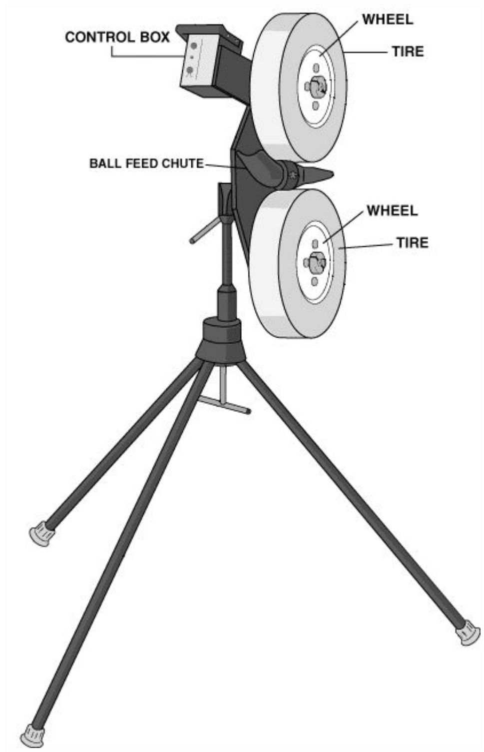

Figure 3: A traditional base ball throwing machine
http://www.sportsauthority.com/graphics/info/shared/BG_baseball_pitching_machine.gif

By rotating the two wheels in horizontal plane, the idea was that the puck would be propelled by spinning the wheels in opposite direction such that tangential component of the wheels' acceleration point towards propulsion. Additionally, since both wheels would have to be powered independently. The resulting RPM of the shooting mechanism could become quite large, theoretically propelling the puck at high speeds. However, due the use of two sets of wheels and motors. Resulting mechanism would far exceed the maximum dimensions of the robot and would be complex to control since the wheels would have to rotate the same RPM to guarantee that puck moved in straight line. Although this design would provide excellent puck velocity, its drawbacks were too plentiful to ignore. See *Table 1*.

Pros	**Cons**
• Puck Maneuvering • Better Aim • High torque	• Precision • Oversize • Complicated control

Table 1: Baseball pitching analogous design considerations

1.2b Orbiting Arm

Our other approach, and the one ultimately used in the final design, was the use of an orbiting an orbiting arm which would hit the puck using paddle. By using a DC motor, we would be able to rotate the arm counter-clockwise and clockwise as desired. Thus, providing unrivaled flexibility in the positioning of the robot for puck contact. However, due to the tether connected to the robot in order to control it, the sector in which the arm could rotate through had too limited by the way of using wooden stops. This was done to prevent the self-mutilation by the arm. Figure 4 below is the Solidworks model the orbiting arm.

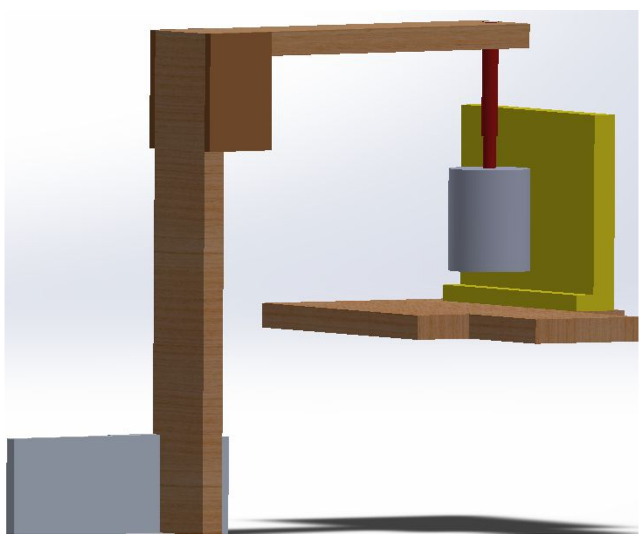

Figure 4: Orbiting arm

Pros	**Cons**
• Bi-directional swing • Robust	• Aim • Full Sweep

Table 2: Orbiting arm design considerations

1.3 Catching Mechanism

1.3a Baseball Pitching Machine Analogous (BPMA)

BPMA for catching was initially considered to complement BMPA hitting mechanism as they work on the same principle. We would align the robot close to a stationary puck and spin the wheels opposite to hitting mechanism to collect the puck. Again, due to complexity of the design and required precision to successfully implement this feature we had to scrap BPMA and look for alternatives.

Pros	**Cons**
• Puck is ‘shield’ from opponents	• Catching Precision • Size • Friction may not big enough to catch the puck

Table 3: BPMA design considerations

1.3b Pinning Mechanism

A second design we considered for collecting the puck was the use of a pinning mechanism. The pinning mechanism would lower itself, apply pressure to the puck, and allow the robot to drag the puck along. To release the puck, the pinning mechanism would raise itself and the puck would be dislodged. The pinning mechanism is implemented using a gear attached to a motor, and a gear rack on the pin itself. Figure 7 below shows the solidworks rendition of the pinning mechanism. Inconvenience to implement this design as the gears had to mate very precisely in order for the mechanism to work reliably was the major shortcoming. Additionally, the pinning was not always observed to be as precise as we anticipated it to be. However, the trade-off of taking less space on the base made it our catching mechanism of choice.

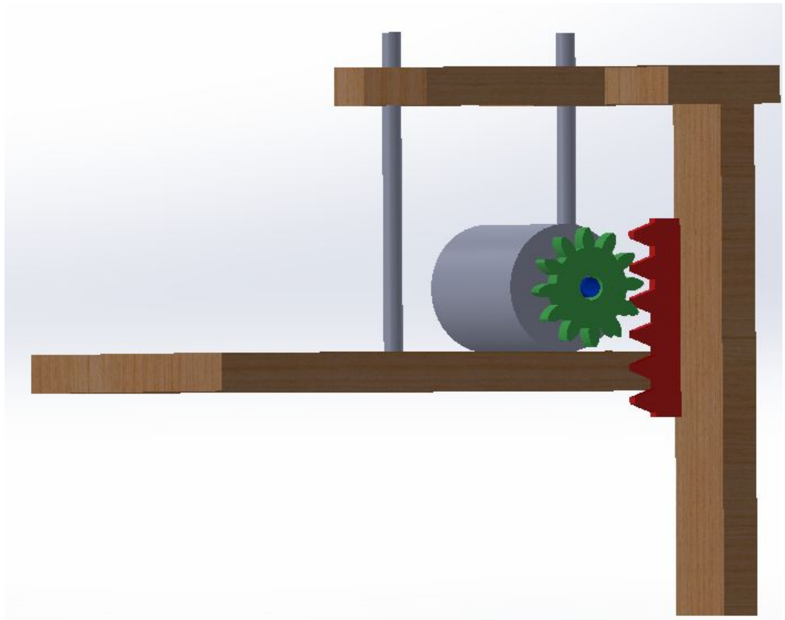

Figure 5: Pinning mechanism

Pros	Cons
• Size fits the design • Easy to control	• Fragile Gear Contact • Precision

Table 4: Pinning mechanism design considerations

2.0 Size Synthesis

2.1 Mobility

The main constraints on the size of the mobile platform was the 10x10x10 cm requirement. The drive motors and corresponding wheels were quite large (6.2 x 2 cm and 7cm diameter, respectively), and had to be factored into the size of the overall mobile platform. As such, the mobile platform was chosen to be a 6x10 cm base as seen in the sketches found in the appendix below. The overall size of the base had to be carefully considered in order to minimize the distance the orbiting arm had to clear. Additionally, enough clearance had to be accounted for in order to properly position the U bracket guide completely underneath the chassis. By placing the guide wheels fully underneath, or as close as possible, the total dimensions of the chassis would be minimal and provide a more suitable center of gravity.

2.2 Hitting Mechanism

The initial idea was that the orbiting arm would sweep completely around the entire robot in both directions. However, due to the presence of the control tether. The sector of the circle in which the arm would rotate though had to stopped. This was accomplished by using two wooden stoppers that had to just long enough to arrest the rotation of the arm but not be long such that the added weight would unbalance the entire assembly. Additionally, the upper segment of the arm had to have radius of at least 10 cm to clear the farthest part of the robot away from the center of the robot (i.e. the two drive wheels) in order to have an unobstructed rotational path. Due to the location of the motor for the arm, the arm would need to compensate for the vertical displacement above the base. In addition to being 10 cm outward, the arm also had to be 11.7 cm tall in order to be able to strike the puck on the tabletop. At the end of the arm, a paddle was used to hit the puck. The size of the paddle was designed to ensure it was able to strike the 45 mm in diameter puck to be used.

2.3 Catching Mechanism

The catching mechanism was one of the last features designed and implemented in the overall design. As such, we had to work around some constraints, one of them being size. The catching mechanism needed to be small enough to not impede the motion of the orbiting arm of the hitting mechanism. With this restriction in mind, the catching mechanism was designed to be vertically oriented in order to reduce the space required. The actual pin of the catching mechanism is 1.5 x 9 cm long. The catching mechanism is built directly above the base to further reduce footprint of the robot.

3.0 Kinematic Analysis

3.1 Mobility

By research, we got the speed of the GM9 143:1 motor is 78 rpm at 6v (http://www.spikenzielabs.com/Catalog/index.php?main_page=product_info&products_id=366). By transferring the speed, we get ω_L is around 8.71 rad/s. Since the radius of back wheel is 0.035m, the speed of this car is about 0.29 m/s. Table 8 shows the specific numbers of all the variable we considered during analysis.
Of course, there will be kinetic friction between wheels and air hockey table surface, but in our design the motor keeps rotating which will maintain its speed and ignore the effect of friction.

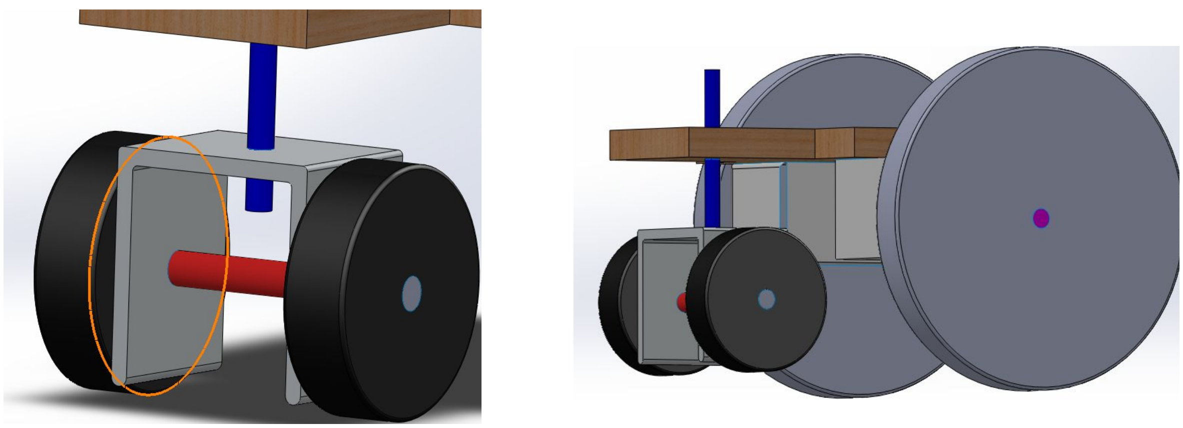

Figure 6: Front and back wheels

Variable	Symbol	Value
Angular Velocity Left Drive Wheel	ω_L	8.17 rad/s (V= 6v)
Angular Velocity Right Drive Wheel	ω_R	8.17 rad/s (V= 6v)
Angular Velocity Guide Wheel	ω_G	9.86 rad/s
Angular Velocity Guide Shaft	ω_{GS}	9.86 rad/s

Table 5: Variables determining kinetic analysis for mobility

3.2 Hitting Mechanism

We use the large motor for hitting mechanism in order to get the high torque. By research, the speed of this motor under load is 600 rpm, that is around 62.83 rad/s. Since the total length of arm is 0.145 m, so we can calculate the speed of the shooting part is about 9.11 m/s. Table 9 shows all the details about the analysis.
Since the arm cannot go all the way around, we also designed two stop break at the back to control arm only rotation in a certain degree, which is around 300 deg.

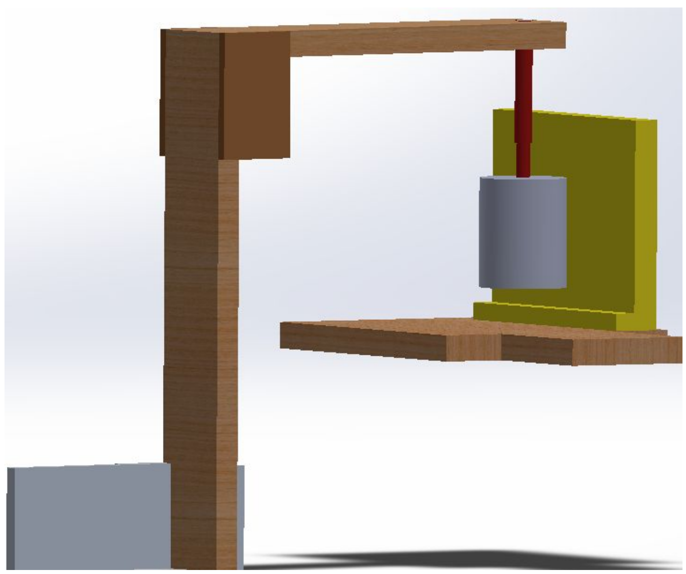

Figure 7: Hitting system

Variable	Symbol	Value
Arm AngularVelocity	w_{arm}	62.83 rad/s (600 rpm)
Arm Mass	M_{arm}	0.02 kg
Arm Radius	R_{arm}	0.145 cm
Arm Linear Velocity	v_{arm}	$v_{arm} = R_{arm}w_{arm}$

Table 6: Variables determining kinetic analysis for hitting mechanism

3.3 Catching Mechanism

For the catching mechanism, we used the medium motor, which has speed under load 450 rpm. And after changing the unit, we got the angular velocity is around 47.12 rad/s. The radius of the gear attached to the motor is 0.7 cm, so we can get the speed of the red gear is 0.33 m/s. Table 10 below has all the information about catching mechanism.
In order to stop the top arm, we designed two rubber break above the two metal shaft.

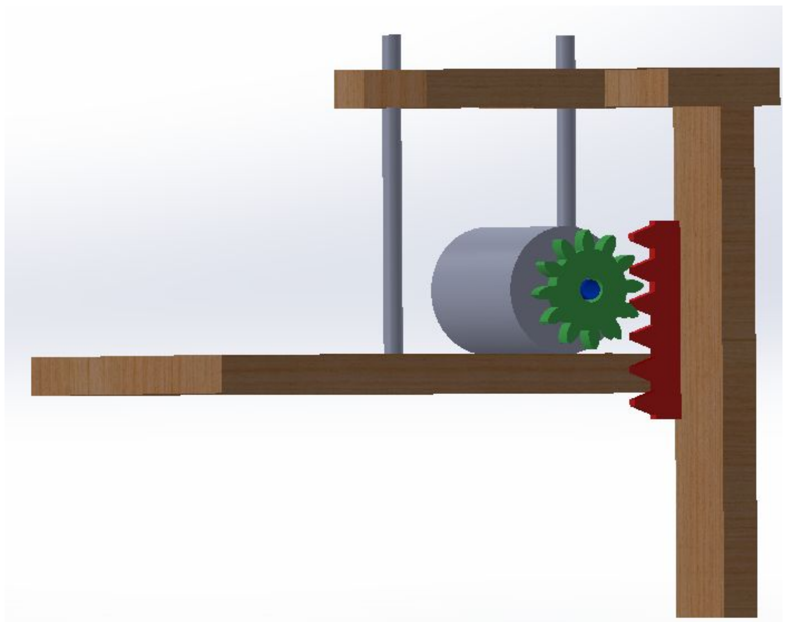

Figure 10: Catching system

Variable	Symbol	Value
Angular Velocity Motor	ω_m	47.12 rad/s (450 rpm)
Gear Radius	R_{gear}	0.007 m
Linear Velocity Pin	v_p	$v_p = R_{gear} w_m$

Table 7: Variables determining kinetic analysis for catching mechanism

4.0 Puck Impact Model & Dynamic Analysis

We listed all the factors we considered for the puck impact in the table 11. In the ideal condition, we set there is no friction between puck and the table, and there is no energy lost during transfer. As we can see, the mass of the puck is less than our arm, so the shooting system will give the puck a larger velocity than the bottom of the arm as well. The formula shown below.

Variable	Symbol	Value
Puck friction	f_{puck}	Zero
Arm AngularVelocity	w_{arm}	62.83 rad/s
Arm Mass	M_{arm}	0.02 kg
Puck Mass	M_{puck}	0.005 kg
Arm Radius	R_{arm}	0.145 m
Puck Linear Velocity	v_{puck}	Constant
Arm Linear Velocity	v_{arm}	$v_{arm} = R_{arm}w_{arm}$

Table 8: Variables for Puck impact Model

Assuming there is 100 percent transfer of kinetic energy from the arm to the puck and negligible friction.

$$\frac{1}{2}M_{arm}v_{arm}^2 = \frac{1}{2}M_{puck}v_{puck}^2$$
$$v_{puck}^2 = \frac{M_{arm}v_{arm}^2}{M_{puck}}$$

Since $M_{arm} > M_{puck}$, we can conclude that $v_{puck} > v_{arm}$

Dynamic Analysis

The energy of our hitting mechanism starts from the DC motor equipped orbiting arm, and is transferred to the hockey puck. During this motion, the puck undergoes several forces that can be explained with the equations included above. By using relationship between the power of the DC motor and the its angular velocity, see *Equation 1*, it is possible to calculate the total torque generated by the motor.

$$\tau_{motor} = \frac{P_{motor}}{\omega_{motor}}$$ Equation 1

The motor generates a torque in the orbiting arm. This torque is related to the moment of inertia and the angular acceleration by Newton's second law for rotation:

$$\tau_{motor} = I_{arm}\alpha_{arm}$$ Equation 2

Using this relation, the moment of the inertia of the arm can be calculated, and the angular acceleration can be found. From the angular acceleration, the tangential component of the linear acceleration of the puck can be calculated since we know the mass of the arm and we can find the center of mass.

$$a_{arm_t} = r_{center\ to\ paddle}\ \alpha$$ Equation 3

In the case of our hitting mechanism, orbiting arm, the acceleration we are mainly concerned with is the tangential acceleration. This is the component of acceleration that will have the largest effect on the puck. Thus, it is possible to determine the total amount of force which would generated at the paddle of the arm by *Equation 4*.

$$F_{arm} = m_{arm}a_{arm_t}$$ Equation 4

Assuming that 100% of the force is transferred to the puck, we can then calculate the acceleration of the puck by using *Equation 4* but with mass of the puck instead.

$$F_{puck} = \frac{m_{puck}\ x\ r_{center\ to\ paddle}\ x\ P_{motor}}{I_{arm}\omega_{arm}}$$

5.0 Solidworks

The following images are of the solidworks rendition of the air hockey robot designed and implemented by members of team 1. The dimensions are to scale, and the assembly can can be found as a single part in the submission package.

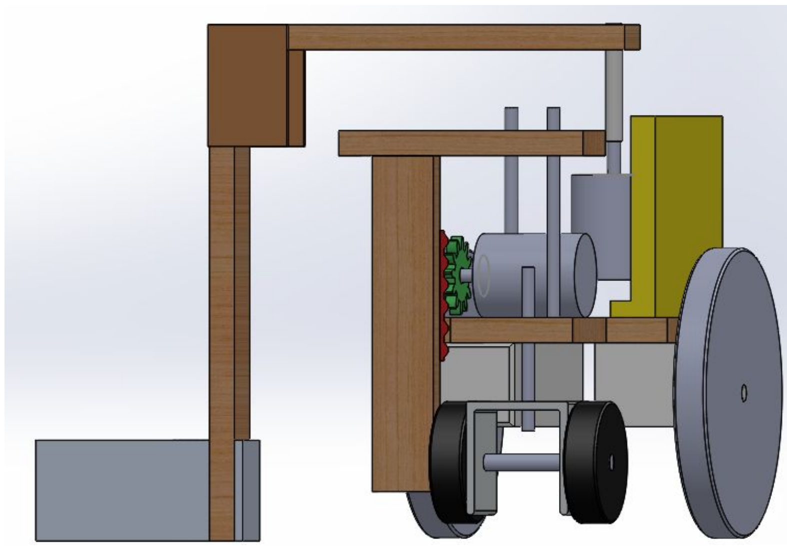

Figure 11: First view of solidworks rendition of air hockey robot

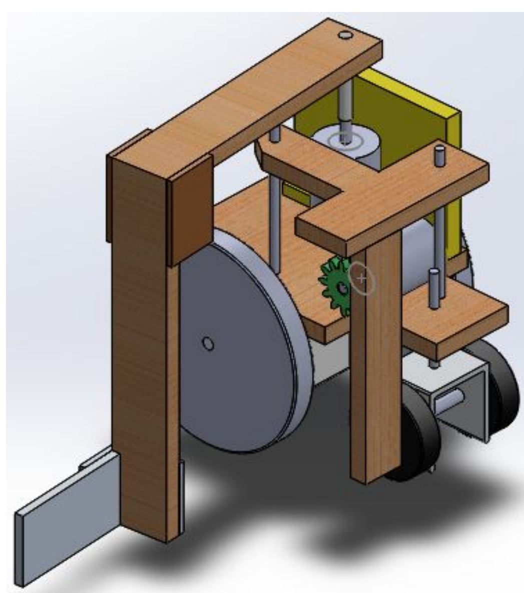

Figure 12: Second view of solidworks rendition of air hockey robot

Appendix

Sketches

The figures below are of the sketches completed both prior to and after the completion of the design. These sketches were used for the design of the physical robot and the solidworks rendition.

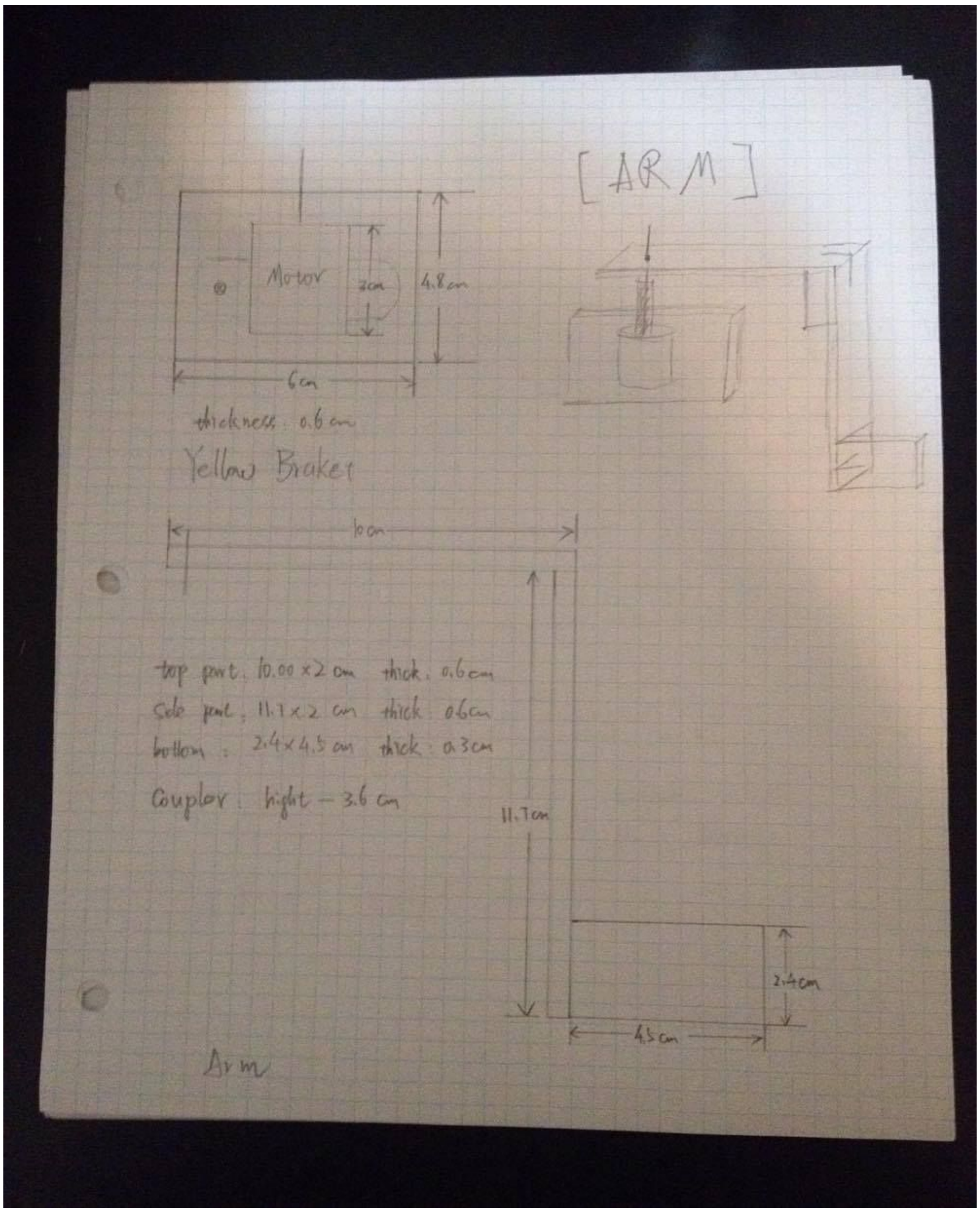

Figure A.1: Arm assembly

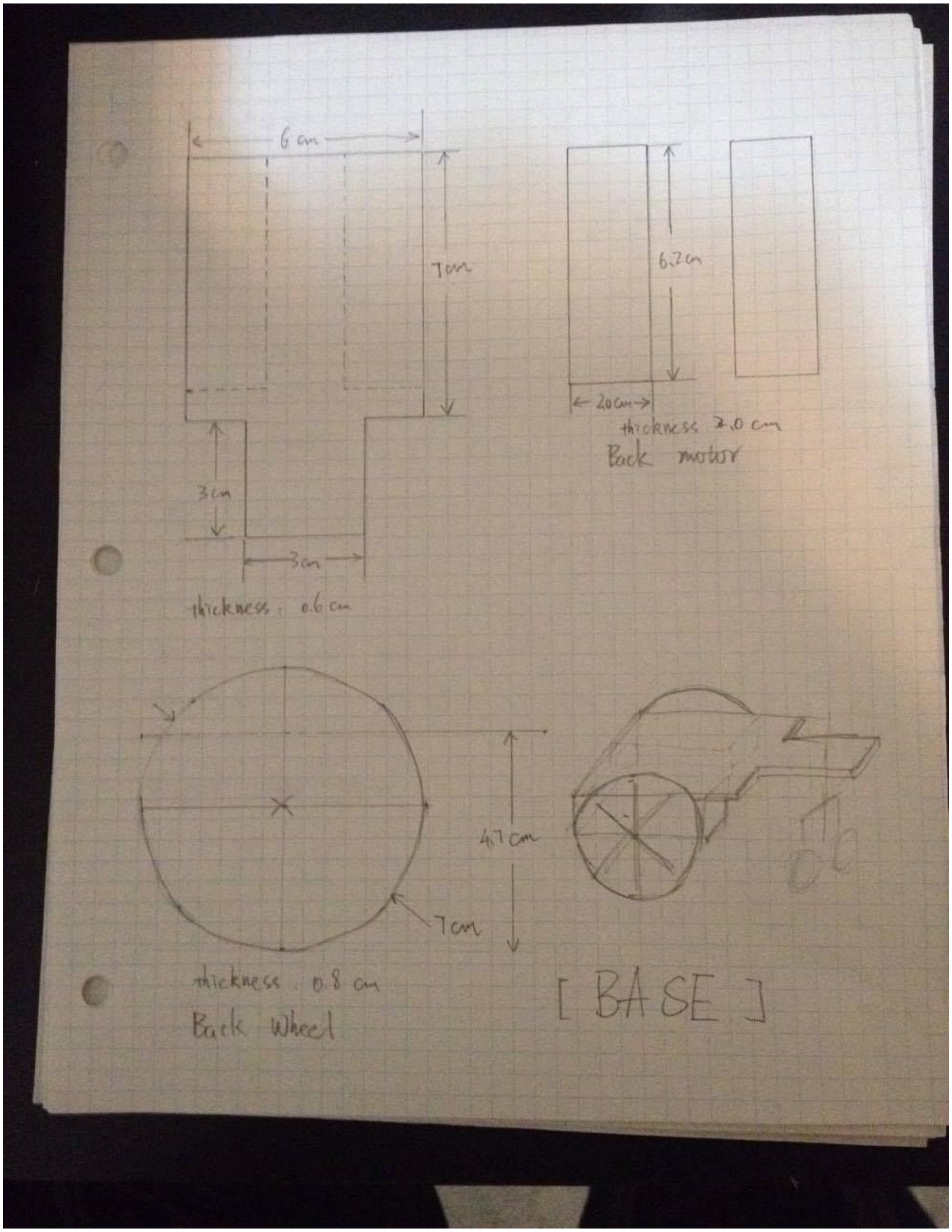

Figure A.2: Base

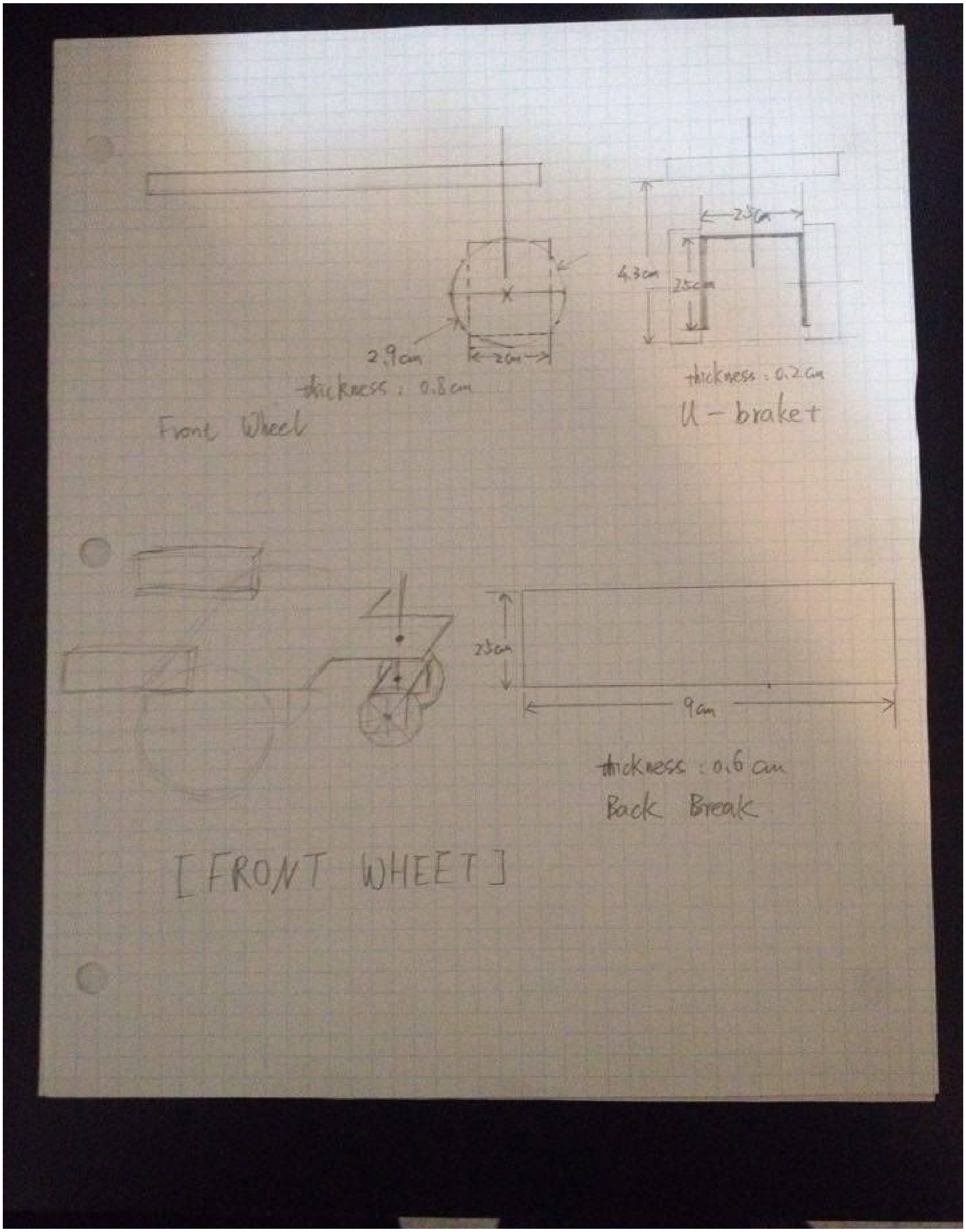

Figure A.3: Front wheel assembly

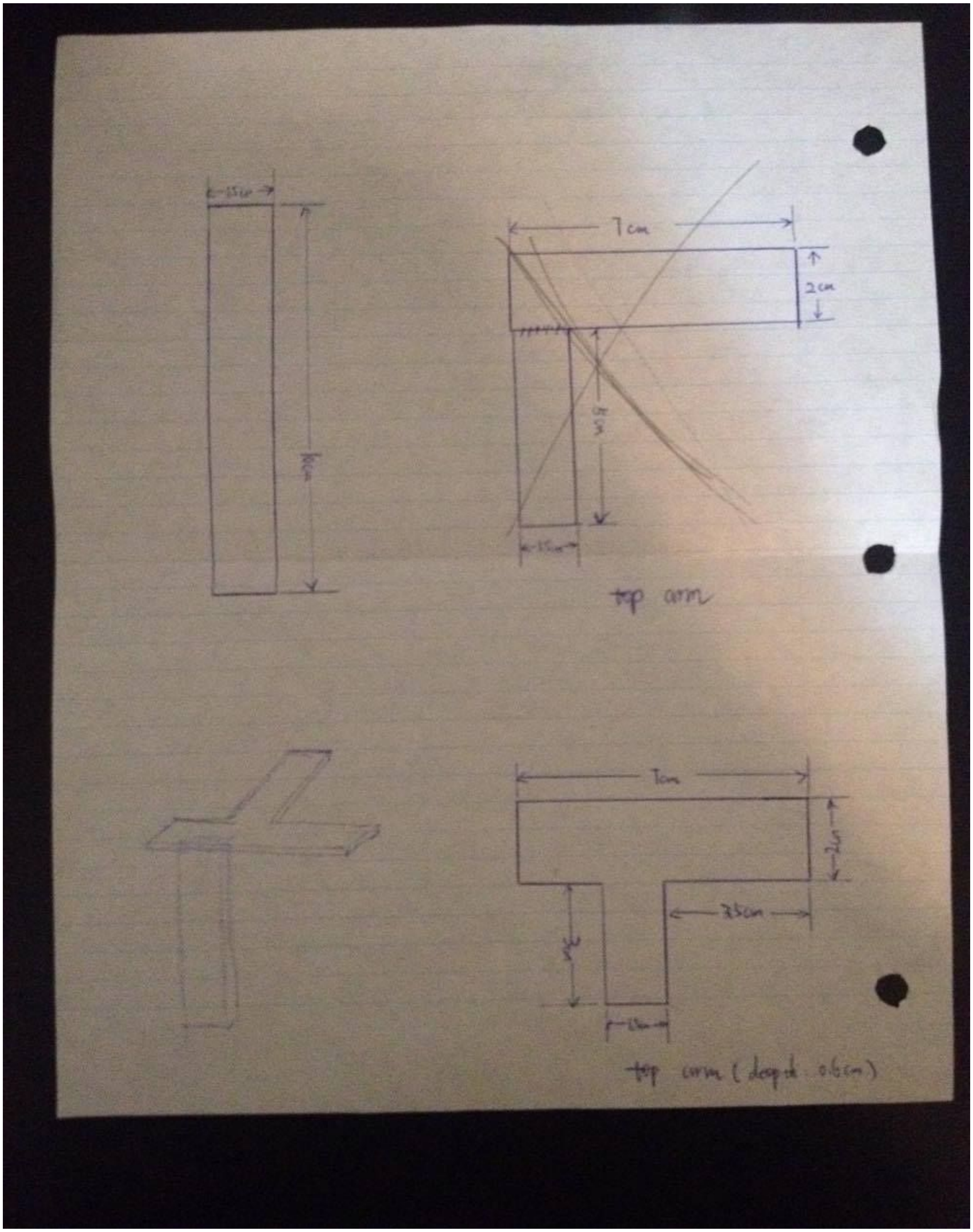

Figure A.4: Pining arm mount