MAE 3 Fall 2024

Team 17 Final Robot Report

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B01

Robot Overview

Boxbot, our robot for this Interstellar Robot Competition, can intake and deposit all three types of planets during the competition (Figure 1). Boxbot has four main components: a drivetrain consisting of a friction drive, a box collector with three side walls and a rotatable trapdoor on the bottom, an arm extension that can grab asteroids and comets, and a swatter system that can tilt the event horizon to our favor for planet deposit and create meteor shower.

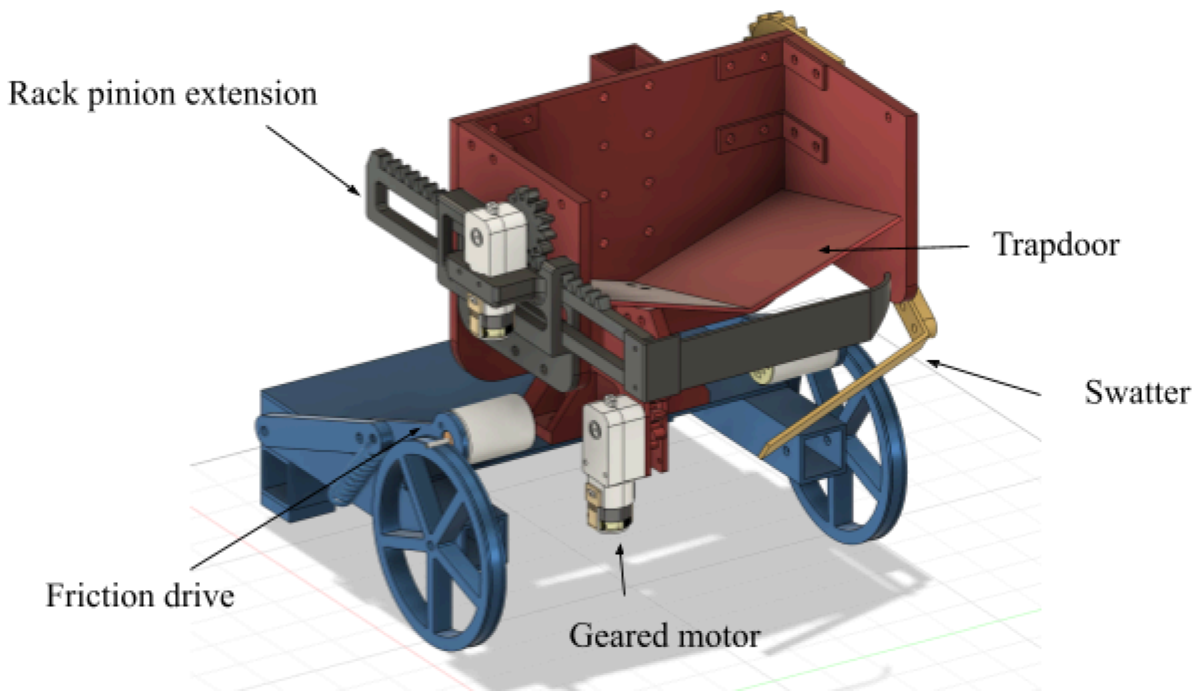

Figure 1. Boxbot CAD

Figure 1 shows that the two non-geared motors are attached to a spring system that pulls down on the wheels. Two medium-sized rubber bands are wrapped around each wheel to generate friction when the motor spins, resulting in smooth turns and driving. With the rack-pinion extension system, the front arm can extend and retract to collect comets and asteroids from the asteroid belts and pull them back to the trapdoor. The trapdoor collects all meteors, asteroids, and comets and is connected to a geared motor system underneath. The swatter is connected to the motor and side wall of the box collector. It can perform rotation to tilt the event horizon for deposit purposes and create a meteor shower by tilting the meteor swing holders.

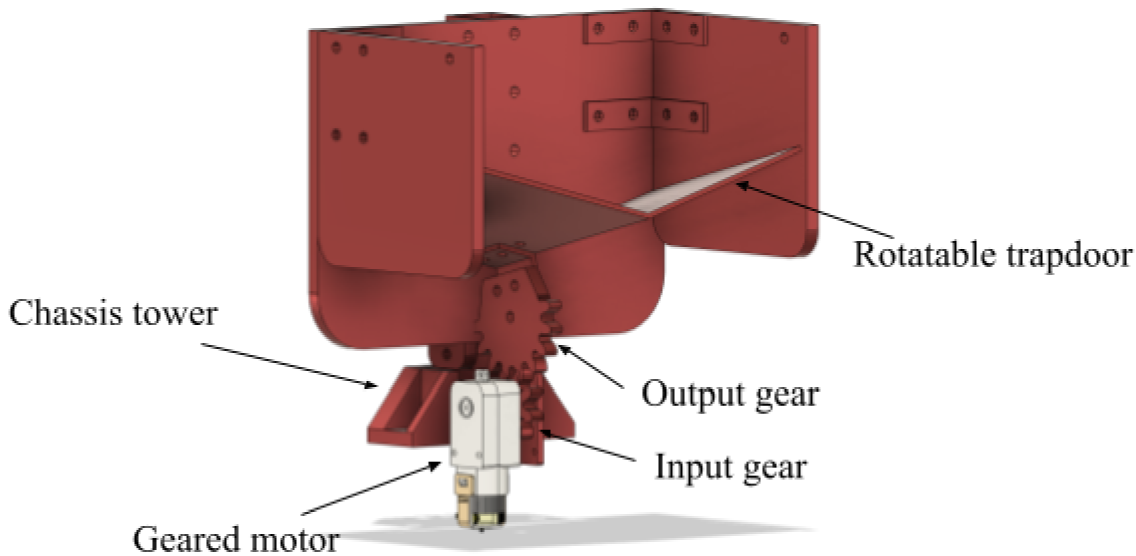

Figure 2. Box Collector

The box collector in Figure 2 is the main component of our robot because it is our intake and outtake mechanism. Without this collector, we cannot score any points. Therefore, it is crucial to prove that the trapdoor connected to the gear-motor system can perform rotation and deposit objects collected. On one side of the bottom of the trapdoor, a large output gear is connected to a racket. The output gear is then lined up with a smaller input gear that is connected to the geared motor. On one side of the gears, a gearbox is designed to provide support. When the motor spins, the input gear spins, resulting in the rotation of the output gear and bringing the trapdoor up and down. The trapdoor must be able to open and close when needed in less than 1.5 seconds. The box can hold the mass of all meteors, comets, and asteroids (0.480 kg) and perform rotation with those weights in it. The geared motor has sufficient power and energy to support trapdoor rotation. This makes sense because geared motors usually have high power and energy.

Analysis of Box Collector

Since the box collector is the main component of our robot, this analysis will be working to determine the maximum mass that the trapdoor of the box can hold while connected to a motor through gear systems. The total mass prediction is determined by the maximum motor torque. These are the used assumptions for the calculations:

- Quasi-static: ignore the force tangent to each gear in the gear system because the input gear is fixed to the chassis (conservative)
- Friction: there is no friction between gears (optimistic)

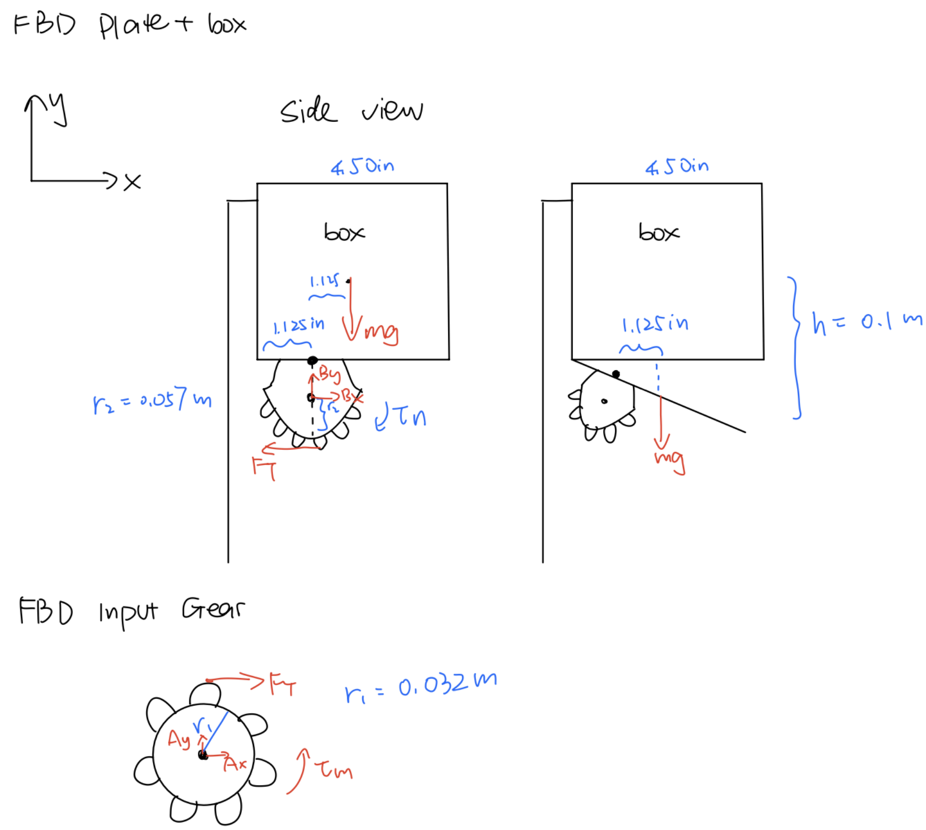

Figure 3. Free Body Diagrams of the Box with Trapdoor Plate (top) and Input Gear (bottom)

First, we wanted to prove that the geared motor has relatively sufficient power and energy by performing power and energy analysis:

Energy Analysis

$\omega = \pi\, rad/s$

$\omega_{max} = 2\omega = 2\pi\, rad/s$

The trapdoor is 0.06 kg. Since the box deposits every time after collecting either meteors, asteroids, or comets, the mass m we use to calculate is the largest assumed mass for one trip: the mass of all meteors is 0.24 kg.

Distance from the center of mass to the rotation axis is d = 1.125 in = 0.029 m

$$E = \frac{1}{2} I\omega_{max}^2 + mgh = \frac{1}{2}(0.06kg * (0.029m)^2)(2\pi)^2 + 0.240kg * 9.8N/kg * 0.1m = 0.236J$$

Factor of Safety for energy is

$$F.S. = \frac{Energy\ available}{Energy\ needed} = \frac{33.6J}{0.236J} = 142$$

Power Analysis

The time we need to rotate half a revolution is about 0.75 seconds, so the full revolution is 1.5 seconds.

$t = 1.5s$

$$P = \frac{E}{t} = \frac{0.236J}{1.5s} = 0.157W$$

Factor of Safety for power is

$$F.S. = \frac{Power\ available}{Power\ needed} = \frac{0.56W}{0.157W} = 3.56$$

Torque Analysis

$\tau = mgh = 0.240kg * 9.8N/kg * 0.1m = 0.235Nm$

Since the output gear does not have the same radius as the input gear,

Input gear: $r_1 = 0.032m$

Output gear: $r_2 = 0.057m$

Gear ratio: $\frac{r_2}{r_1} = \frac{0.057m}{0.032m} = 1.78$

Factor of Safety for torque is

$$F.S. = \frac{Torque\ available}{Torque\ needed} = \frac{0.28Nm}{0.235Nm} * 1.78 = 2.12$$

Summary of Power, Energy, and Torque Analysis

From the calculations above, we proved that the geared motor has enough power and energy to support the rotation of the bottom plate trapdoor since the factors of safety are 142 and 3.56, respectively. However, the factor of safety for torque is 2.12, which is less than 3. Further calculations and experiments are needed to ensure that the robot can perform what we want. We used Quasi-static analysis to calculate the maximum mass the box can hold by the motor.

Quasi-Static Analysis

From Figure 3, the following equations can be derived:

$$\sum F_x = F_T + A_x = 0$$

$$\sum F_y = mg - A_y = 0 \Rightarrow A_y = mg$$

$\sum M = \tau_n - mgd = 0$ where τ_n is the torque of the output gear

$$\tau_n = mgd = m * 9.8N/kg * 0.029m$$

Big output gear: $F_T = \frac{\tau_n}{r_2} = \frac{m(9.8)(0.029)}{0.057}$

Small input gear: $F_T = \frac{\tau_m}{r_1}$

Since the input gear and the output gears are in contact, F_T is the same for both gears.

$\frac{\tau_m}{r_1} = \frac{\tau_n}{r_2}$ and $\tau_m = 0.28Nm$, which is equivalent to the motor torque

$\frac{0.28Nm}{0.032m} = \frac{m*9.8N/kg*0.029m}{0.057m}$

$m = 1.755kg$

The calculated maximum mass the box can hold for trapdoor rotation is 1.755 kg, which is higher than the mass of all the objects we need to collect during the competition (0.480 kg) and also higher than the theoretical mass we want to hold in each trip (0.240 kg).

Experiment to test the maximum mass that can be held

In order to test the maximum mass that the robot box collector can hold, we add weights on the trapdoor (Figure 4) and record whether the motor connected to the gear system could perform rotation or not in Table 1. We will start by adding 0.10 kg every time and record in a table until the motor stops functioning and can not tilt the plate anymore.

Table 1. Mass on the trapdoor and motor rotation

Trials	Mass on the trapdoor (kg)	Motor rotation (yes or no)
1	0.10	yes
2	0.20	yes
3	0.30	yes
4	0.40	yes
5	0.50	yes
6	0.60	yes
7	0.70	no
8	0.65	yes
9	0.69	yes
10	0.71	no

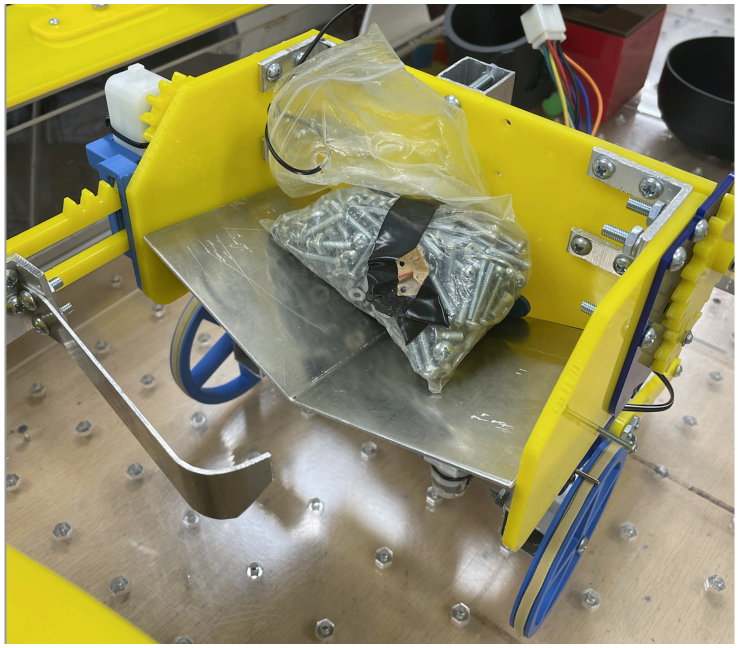

Figure 4. Maximum mass experiment

The actual value of the mass the trapdoor can hold is 0.70 kg, which is lower than the calculated 1.755 kg. Despite the fact that the actual value is lower than expected, 0.70 kg is still a good number as it is larger than the total mass (0.480 kg) we can have in the box.

To calculate the realized factor of safety for torque:

$m = 0.70kg$

$\tau_{available} = mgh = 0.70kg * 9.8N/kg * 0.1m = 0.686Nm$

$F.S._{Realized} = \frac{0.686Nm}{0.235Nm} * \frac{0.057m}{0.032m} = 5.2$

From the experiment, we obtain a factor of safety of 5.2 for motor torque. 5.2 is larger than 3, so the geared motor we used can generate enough torque to hold the weight and perform rotation during the competition smoothly.

Overall Conclusion

From the above calculations on energy, power, and torque of the motor on the box component, we conclude that the geared motor we used can perform the required tasks successfully. In the original energy, power, and torque calculation, the factors of safety are 142, 3.56, and 2.12, respectively. Since the factors of safety of energy and torque are larger than 3, we conclude that the motor has enough power and energy to perform rotation. Since the factor of safety of motor torque is 2.12 < 3, we conducted a Quasi-static analysis to find out the maximum mass the trapdoor can hold with the motor being able to rotate successfully. The expected mass it can hold is 1.755 kg, which is larger than 0.480kg, the sum of all meteor, asteroid, and comet mass we can collect during the competition. To test the reliability of the expected value, an experiment was conducted by adding 0.1 kg mass every time to test rotation. The experiment shows that the maximum mass the trapdoor can hold is 0.70 kg. 0.70 kg is lower than the expected 1.755 kg. The possible reasons are that there may be friction between the gears and the motor, the distribution of the mass is not centered at one point like what the calculation assumed, and the motor may not have the exact same condition as the new gear we tested at the beginning. Considering the robot as a whole, we tested that Boxbot could score a maximum of 200 points within the 1-minute time range if nothing unexpected happened when driving. Thus, Boxbot can be considered a good design because it can score all three types of planets (meteors, asteroids, and comets). One limitation is that since we had 5 motors and 4 power sources, the swatter and the arm extension were in parallel. When collecting the asteroids or comets from the asteroid belt, they interfered with each other and caused unnecessary friction that prevented the arm to extend and retract. If I had a second chance, I would design a better drivetrain for our robot because friction drive is not always reliable. We used rubber bands to create friction between wheels and motors, but the rubber bands tended to slip off so the robot could no longer move. The biggest technical challenge during the design process was to create a support system for the motor that is attached to the bottom of the trapdoor through the two-gear system. I learned how to apply equations on power and energy to calculate factors of safety of my powered component and how to increase the factor of safety by changing gear ratios. In this robot project, the major growth for me was that I learned how to apply what I learned from physics class in the past to real robot analysis and solve problems with physics. I am proud of the work my team and I put in throughout the past 7 weeks on this robot project, and I think our robot represents what we learned and has the potential to score from all three planets.

Design Process

During the second week after the start of this project, our team changed the entire robot design many times. At first, the robot had an elevator design that could carry the box up and down to collect objects, so no swatter was needed. Our team discussed the ideas and drew lots of sketches in the library together to figure out what was the simplest way of modifying the robot so that it could perform all the tasks with minimum complexity. For my component, I designed a simple box that was attached to a rotatable joint connected to the tower of the chassis first. The joint could perform rotation and the bottom of the box did not need to rotate. I sketched the first idea and discussed it with my teammates. After a four-hour straight group discussion, we abandoned the original idea of elevator design with a rotatable box and replaced it with a rotatable bottom plate on a fixed-height box. It was a huge conceptual breakthrough because the elevator design was very hard to apply in real life and required high motor precision and accuracy. Even though this long discussion completely undermined what one of my teammates had designed, this simpler new design gave us more control when driving the robot and lowered the amount of risk in our design.

Without the original elevator design, my box component became the component with the highest risk because it was the main intake and outtake mechanism that needed to collect everything to score points. After confirming that we were designing a box with a rotatable bottom, our team performed a risk reduction test (Figure 5).

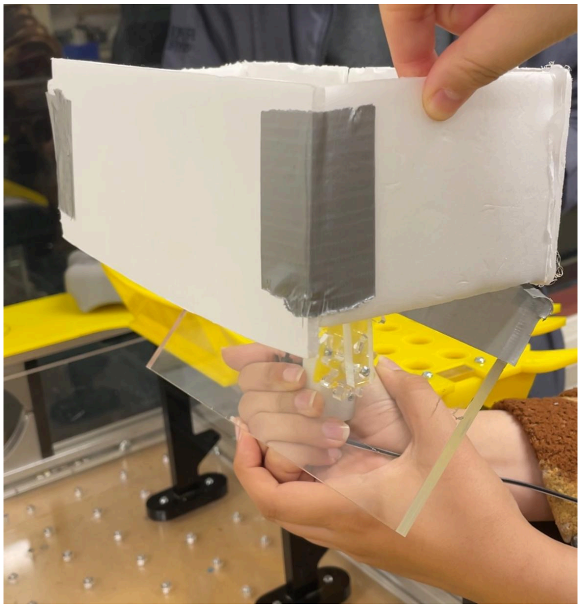

Figure 5. Box Risk Reduction

We used foam boards as the box and clear acrylic as the bottom plate. We tested that the motor with two gears can successfully rotate the bottom plate to deposit items collected. However, we found that since the bottom was flat, the objects rolled out randomly to all directions and could not deposit to the event horizon accurately. Therefore, we changed the bottom plate trapdoor to sheet metal and bent it in the middle to create a tilted tunnel to guide the objects when rolling out. We prioritized building the arm extension for the final piece first because the box relied heavily on the drivetrain attach point design. After the arm was built, we assembled the drivetrain and confirmed the attachment point locations on the box. We prioritized building those two components because they had lower risk and gave us confidence in our general robot design. Our team followed the Gantt chart closely but also made lots of changes to the chart as designs changed and were revised. The chart helped us see which step we were on and what to do next. From this project, I learned a lot about CAD design, risk reduction, Design for Manufacturing, and physics knowledge application, and I believe this robot demonstrates our team's effort and ability in robot design and creativity.