A New and Improved Hopper

GNG1103 Project

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Abstract:

Our design team created a design that totally incorporates the robot’s hopper with a filter.

Because wet sand is such an obstacle in the filtering of Bowie’s hopper, our design uses gravity to force the sand out of the hopper. As the sand reaches the bottom of the hopper it is met with a filter, this evacuates the sand from the hopper. The dimensions of this filter were decided on during our multiple rounds of testing. Our filter design bridges the gap between efficient sand removal and retainment of trash. Our design deals with this filtered sand by letting it escape down two opposing ramps. These ramps evacuate the sand and return it to the beach. In order to better the user experience, we have implemented sensors to notify the controller when Bowie’s hopper is full. This addition decreases the number of required interactions between the controller and robot, making use more effective. We believe these additions will benefit the robot and therefore the user, making Bowie a more impactful robot on the beaches of Canada and the world.

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1. Introduction:

This semester our team had an exciting opportunity to design an extension to Bowie, Robot Missions and Erin Kennedy’s flagship bot. Robot Missions is an environmentally focused technology company that is best known for their innovative use of using autonomous robots in order to help the environment. The company realizes the significant budget that the city of Ottawa spends yearly on cleaning public areas such as parks, and beaches and hopes to drastically lower this number via low-cost but efficient technology. Erin showcased to our class her company’s most notable robot, Bowie, which is a small-sized, lightweight, semi-autonomous, low-cost robot whose sole purpose is to observe, clean, and restore the parks and beaches of Ottawa Ontario.

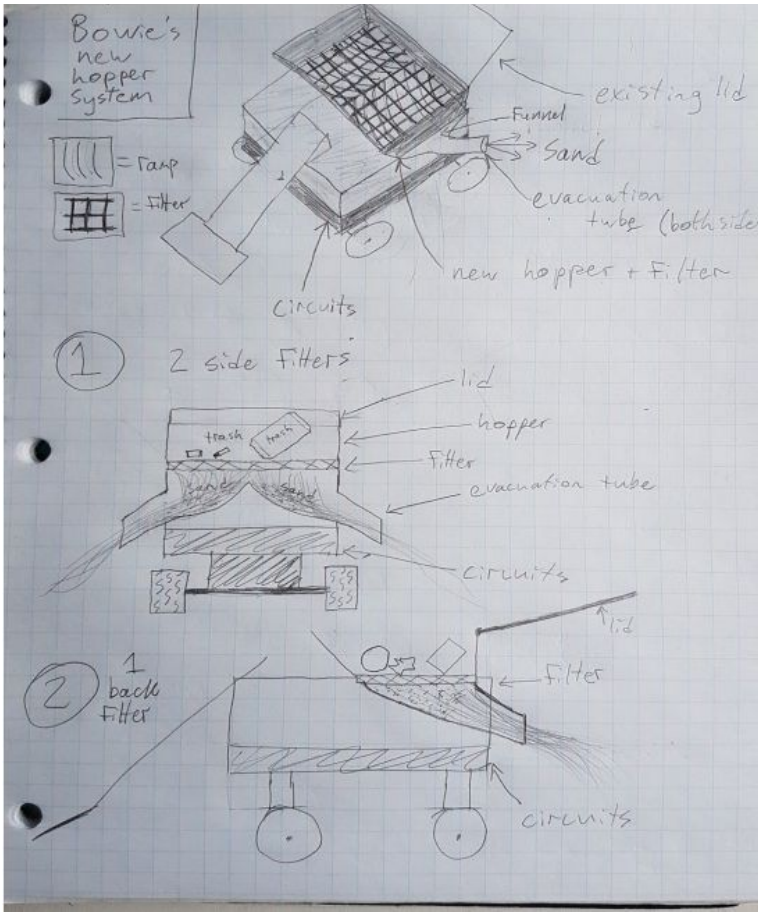
It was made evident that one of the problematic aspects of Bowie was the build up of sand in its hopper. This build up of sand results in less volume being available for litter and thus Bowie is unable to carry its intended capacity of trash prior to being emptied. As a result of this information, our team decided to tackle this significant issue and develop a hopper that featured a filtration system. The implementation of the new design was successfully accomplished by following the process of design thinking.

2. Empathize

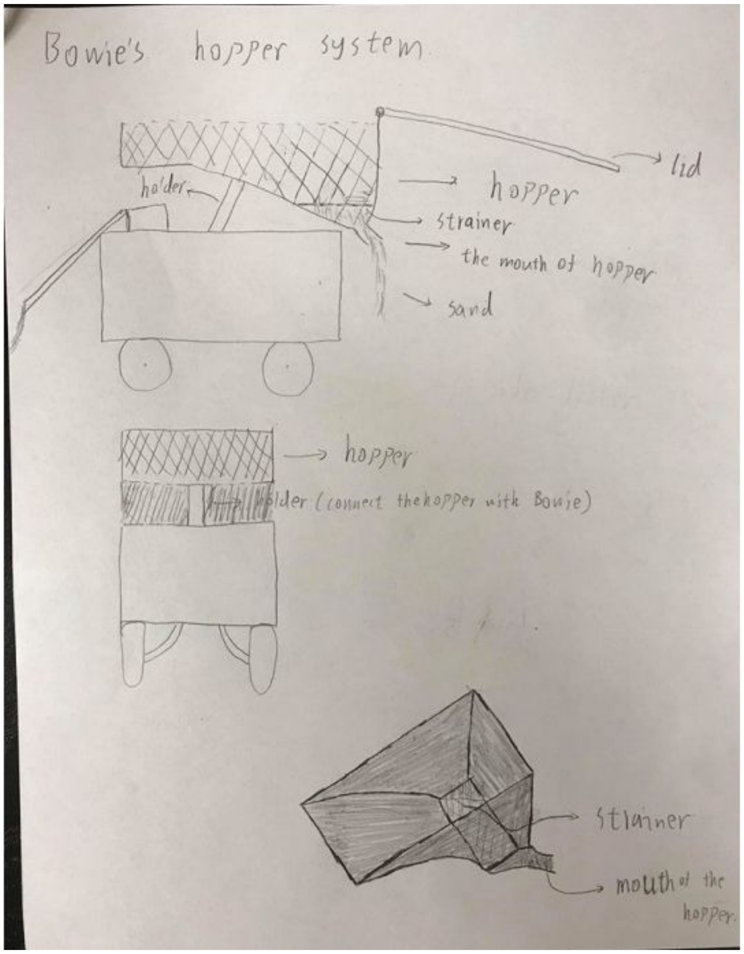
The first client meeting delivered detailed insight on Bowie's most pressing needs, resulting in an altering to our original idea. 3 main focus ideas that stood out from Erin's project presentation: an improved filter, a protective shelter, and a wildlife camera mount. Our team noted that a prominent issue in the design of Bowie's hopper was the buildup of unwanted sand. Since trash is mixed with sand, each time that Bowie scoops up waste, sand is picked up as well. This accumulation of sand in the hopper creates less space for the trash which Bowie is supposed to be storing. Thus, it was determined that a feasible way of solving this problem would be to implement a sand filtration system in the hopper, allowing him to collect more trash before his has to be emptied. In presenting Bowie to the class, Erin showcased many features of Bowie including a description of Bowie's arm and the attached shovel tip which scoops the litter from the beach. This shovel attachment consists of numerous holes which act as a means of filtering any sand out and isolating the litter to be stored in Bowie's hopper. However, it was understood by our team that even with this attachment, Bowie still struggled with the build up of sand in its hopper. This would lead to a portion of the hopper consisting of sand which would impact the amount of trash that the robot could carry. Our team deemed this build up of sand as a significant issue to confront as it impedes Bowie's task because it limits the amount trash it can collect before it needs to be emptied. We especially realized the importance of filtering wet sand from the hopper, since wet sand poses a different problem.

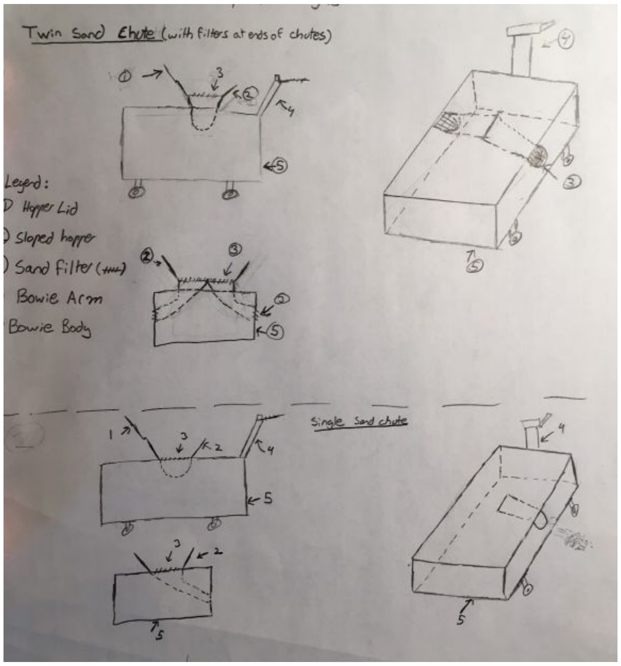
3. Ideate:

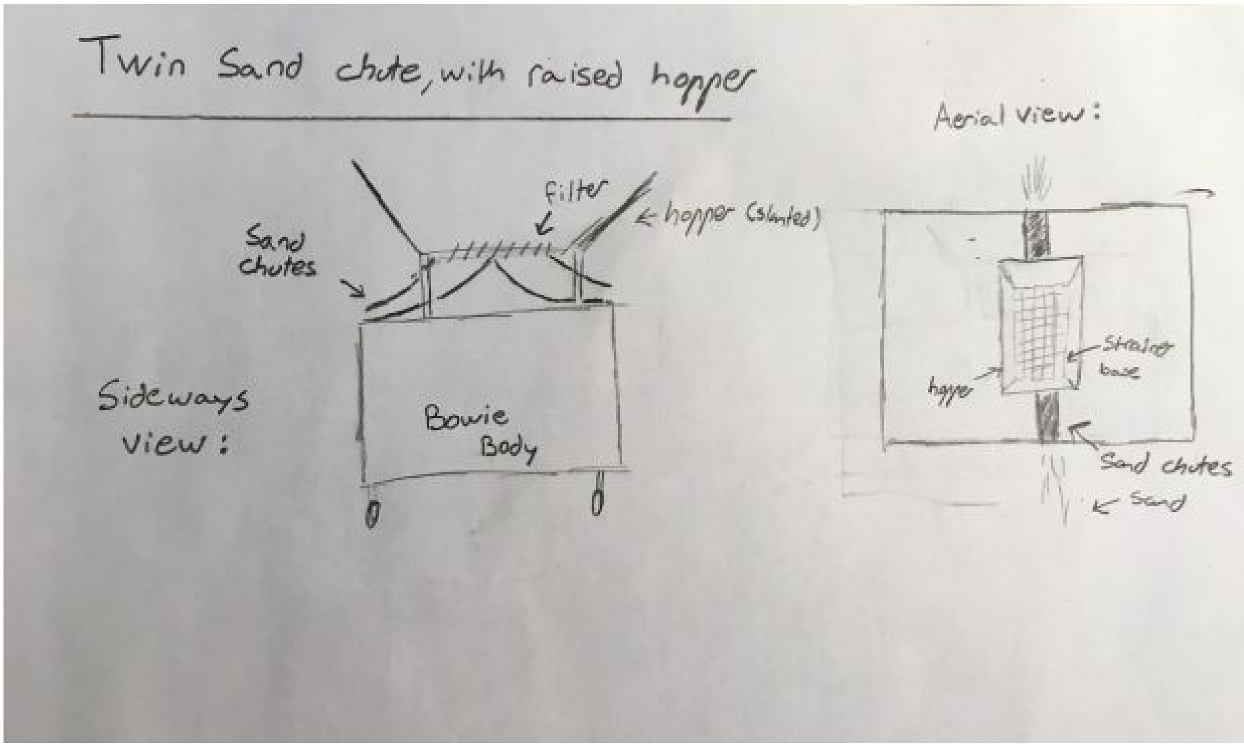
Having identified issue of the sand build up in Bowie’s hopper, we began developing numerous design concepts in the form of sketches. Our team established several design specifications we deemed necessary and weighted each in their respective importance. Each design concept was collectively ranked based on how many specifications they met, leading to the best design being the photo below. The design concept featured an elevated hopper with a filter as the base, and two laterally placed ramps connecting to the base of the hopper with the purpose of guiding the unwanted sand out and back onto the beach. The new hopper’s design was made to be compatible with Bowie’s current mechanized lid in order to order to avoid wasting resources on designing a new lid entirely. Here is a sketch of this design:



A few of our ideas that we did not end up choosing are shown below:


Bowie's hopper system
lid
holder
hopper
strainer
the mouth of hopper
sand
hopper
holder (connect the hopper with Bowie)
strainer
mouth of the hopper.


Twin Sand Chute (with filters at ends of chutes)
①
3
②
4
⑤
Legend:
① Hopper Lid
② Sloped hopper
③ Sand Filter
Bowie Arm
Bowie Body
②
③
②
⑤
④
③
⑤
1
3
2
4
5
Single Sand chute
3
2
5
4
5


Twin Sand chute, with raised hopper
Aerial view:
filter
hopper (slanted)
Sand chutes
Sideways view:
Bowie Body
Strainer base
hopper
Sand chutes
Sand

4. Prototype:

In our design process, we created 3 different prototypes to focus on aspects of our product. Prototype 1 being a cardboard proof of concept with a focused filter prototype. The second prototype looked to nail down our filter design as well as to implement break beam lasers. Our third prototype and final was a comprehensive prototype.

4. Prototype 1

As our team generated ideas for our first prototype, we determined the we needed test the filter since it is the critical function of the design. Since our idea revolved around filtering out sand, testing out different types of filters with different types of sand was the most logical prototype to first test out. After analyzing the filter, we felt that it was important to test the feasibility of the ramps. We first designed a filter with circular holes and 3D printed it out prior to the lab in order to maximize our time. We then proceeded to build a first draft of the hopper out of cardboard, attaching the filter and the ramps to the bottom. We designed our first prototype to be a scale model of what our final project will be. We decided as a group that a cardboard scale prototype would be the most effective first prototype, since it minimized the time wasted 3D printing while. During the lab we obtained other filters with different hole shapes and diameters and utilized them in our testing process.

4.1 Prototype Test Plan

We followed the following steps in order to create this first prototype

1) Design a prototype filter on Autodesk 360

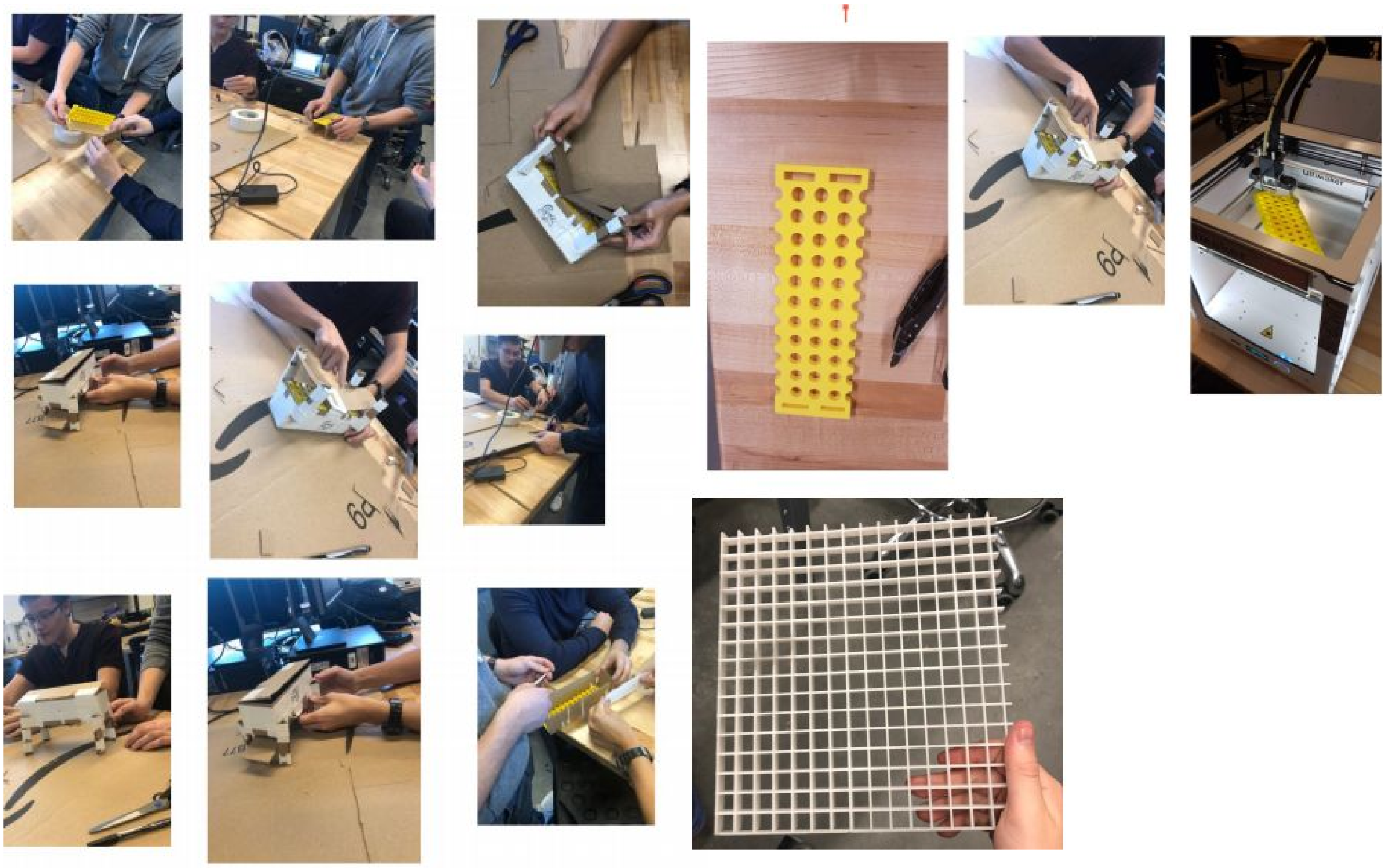
2) 3d print the filter
3) Gather the necessary cardboard
4) Collect cardboard, measure and fit the cardboard to the filter utilizing tape to secure it
5) Cut out stands and tape it to the 4 corners of the hopper
6) Cut out ramps and strategically place
7) Cut and install the rail blockers
8) Collect Sand and wet sand
9) Test and benchmark

One of the largest threats to our design’s success is the clumping of wet sand and it's inability to be filtered out. Because our design revolves around the sifting of sand, it was crucial to have the filter component be tested as soon as possible in order to determine the best way to filter out the wet sand. This prototype was intended to test the filter and learn from it, in order to determine the best filter possible for our design.

As previously stated, the most critical component of the test was determining the effectiveness of our filter. It was paramount that we found if our design eliminate the sand out of the hopper. Once this was complete, it was paramount to ensure that small trash items such as cigarette butts did not pass through the filter along with the sand. The testing of this design gave us knowledge in relation to the filtering ability of our initial design as well as the ability of the filter to retain the small trash contained in the hopper. It was important to understand if there were deficiencies in our design concept from the testing, so we would be able to make the changes from early as possible. An example of this is in the design of the filter. If we discovered that If during the test the filter performed poorly we would need to consider changing the dimensions so as to let more sand pass. If in the case of the filter performing in a way that met our criteria, we would print another version that was in the exact dimensions of our final design product.

In order to properly test our prototype, we needed to first collect sand from a local park.. In addition, we tested the filtering ability of other filters. When we tested the first prototype with wet sand, 3 mock cigarette butts and 2 water bottle caps, the majority of the sand was not able to filter out while the prototype was still. However, when we shook the prototype slightly to simulate the vibrations of Bowie as he moves, all of the sand filtered out of the hopper and down the ramps without any issues, while keeping all 5 items in the hopper. For the next step of the testing, we took wet sand and placed it in the hopper with the same 5 items and shook it slightly to account for Bowie's vibrations. When this happened, we noticed that the wet sand got stuck in the areas between the holes of the filter, and only a partial amount of the sand would be removed from the hopper. This clearly did not meet our hopes.

The next step of testing was benchmarking. We tested filter 2 which was a square grid filter with 1.3 cm x 1.3cm holes. It performed extremely well, removing nearly all sand satisfying our design criteria.



4.2 Analysis of critical components:

The filter

The first filter evacuated the sand significantly less than our target specifications demanded. Having the 1st filter perform at the level it did requires a change in design. The 1's design was oriented towards ensuring trash did not pass, which meant the sand had significant difficulty passing the filter. We determined that the performance of the filter fell well below our requirements and would therefore need to be redesigned. After testing the second filter, which had square holes with dimensions' of 1.3cm x 1.3cm, we determined that a grid filter with similar sized cuts would be ideal for our design. During testing the filter evacuated the sand efficiently while keeping the trash in the hopper meeting all of our specifications. The risk of having trash pass through filter was addressed by having mock cigarettes inside the hopper. Our team used many strategies and situations to try to facilitate the letting through of small trash. Throug all the trials completed, the cigarettes did not pass the filter. Since the second filter met our design criteria, we decided that that this would be the best filter to use going forward

Ramps

In order to properly remove the sand once it falls through the filter, the ramps have to be at a sufficient angle where sand does not stuck on the ramp. However, this angle can not be too steep since it would require the hopper to be raised too much, thus altering the weight distribution of Bowie beyond a comfortable margin (leading to unwanted instability). In order to be certain that wet sand would not get stuck on the ramp, we determined through the testing that the best angle for the ramps is 20-25 degrees.

5. Prototype 2:

The objectives of the second prototype was to combine a comprehensive physical prototype of our sand filtering system and to create a focused physical prototype for the break beam laser. For the sand filtering system, the main goal was to verify the feasibility of the new and improved filter, so that the sand is able to filter out of the hopper. For the break beam lasers, our main goal is to wire, solder and implement the code to the lasers, so that they can be easily implemented in the next prototype. Ultimately, these 2 prototypes give us the majority of our third and final comprehensive prototype.

5.1 Prototype test plan:

Filter

Our goal for this test was to test the filter as well as our assembly's structural weaknesses. Because our prototype was comprehensive, we used it to gain knowledge on the performance of the filter when it was assembled with the other components. Our test involved observations on the overall performance of the system as well as the ability of the filter to evacuate sand.

Laser sensors

In order for the sensors to be successful, their break points and range had to be tested. For the lasers to be implemented an understanding of their abilities had to gained. This test involved developing code for the sensors and then testing the effects of different code in the output. We tested this by setting the lasers to be in alignment then obstructing the beam and analyzing what data was returned on the control monitor.

Analysing critical subsystems:

5.2 Critical subsystems

The critical subsystem of the design of the hopper is the filter. It is paramount to be able filter the sand from the hopper in order to maximize the space in the hopper. After we built the hopper, we tested the filter to make sure that the sand and wet sand was exiting the filter, while maintaining the trash inside. Through our testing, we determined that 90% of dry sand was filtering through the filter. In addition, we determined that 80% of wet sand was filtering through the wet sand. The sand that didn't get filtered out was blocked by trash at the bottom of the hopper and could not leave. The reason less wet sand was able to filter out was because wet sand often got stuck to the trash, whereas dry did not. During this testing, no small or large trash items fell out of the hopper. This is well within our target specifications, as we had made our ideal and acceptable target specifications at 75% and 50%, respectively. We did not implement the ramps in this design as we already verified they work in prototype 1.

In order to improve this prototype from the last one, we changed the filter in the hopper based on our testing and benchmarking that we discovered in the last prototype. Whereas previously we had a rectangular filter with cut-out circles, our new and improved filter was a grid of continuous cut-out squares(see pictures). This change in the filter greatly impacted the removal of wet sand compared to the circle filter, as it was less likely to get stuck between the holes.

Laser sensors

In order to code the sensors, we used the code from arduino that came with the purchase of the sensors. We had to implement tweaks to the code to make sure that “Empty Space” and “blocked” were printed to the serial monitor, along with a 10 second time delay when the sensor was blocked. When we tested the range of the sensor, we discovered that it was about 25 cm using a 5V power input and roughly 22 cm for the 3.3V power input. Upon this discovery, we realized that it was important to use a second laser since the length of the hopper was 30 cm. In addition, we had to solder the wires together. A lot of time and effort was put in to solder the wires properly, as they often kept breaking. A good soldering job ensured that the wires would not break, which would allow the lasers to work as planned.

A key design concept our hopper is the implementation of lasers sensors that are able to determine when the hopper is full and must be emptied. After receiving the break beam laser sensors, we programmed them using Arduino so that the lasers are able to tell Bowie's operator when there is room in the hopper. It says “empty space”, when the laser sensors are not blocked and “Blocked” when the hopper is full. When an object passes through the lasers without blocking the sensors, the message appears as “Blocked” then “empty space” to signify that the item cleared the laser and there is still room . These messages are all printed to the serial monitor of Arduino. Obviously though, when the hopper is integrated with Bowie, there is a need to integrate these messages into the system of Bowie. However, this could not be done at the current phase of our production. In order for the lasers to be properly integrated, it needs a small amount of power from Bowie’s battery. This would also have to be integrated with Bowie, and can not be done right now. Currently, the lasers are connected through the Arduino in order to monitor the messages being printed to the serial monitor. The connection through the computer is the current power supply for the laser sensors.

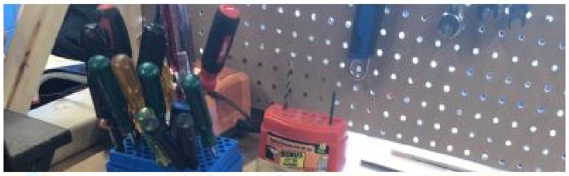
Steps of Laser Implementation
1) Order and receive lasers from https://www.adafruit.com/product/2167
2) Using the arduino instructions on adafruit.com, set up the wires on a breadboard in order to implement the code
3) Implement the code from adafruit.com
4) Edit the code so that it prints “Blocked” and “Empty space” to the serial monitor. Create a nested loop so that when an item blocks the sensor, only after 10 seconds it prints blocked in order to allow items to past by
5) Upload the code using arduino, and test the code by viewing the messages printed to the serial monitor 6) Buy a PCB board from the maker lab and switch the wires from the breadboard to the PCB board 7) Solder the wires together on the PCB board 8) Plug the lasers into the keyboard and test to make sure it is working properly.

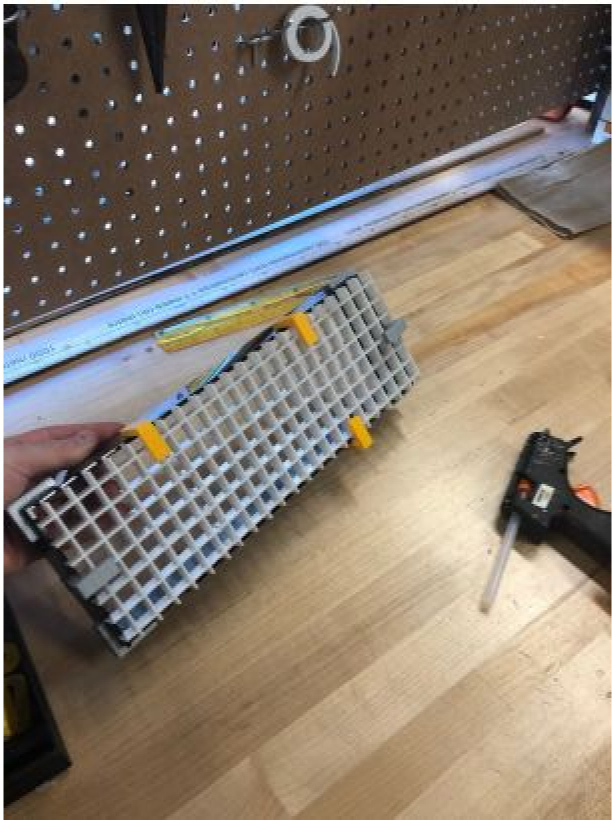
Steps of Physical Design
1) Create vector pdf of the Hopper design using Inkscape
2) Purchase acrylic sheet and laser cut the hopper design out of the sheet using the vector pdf file

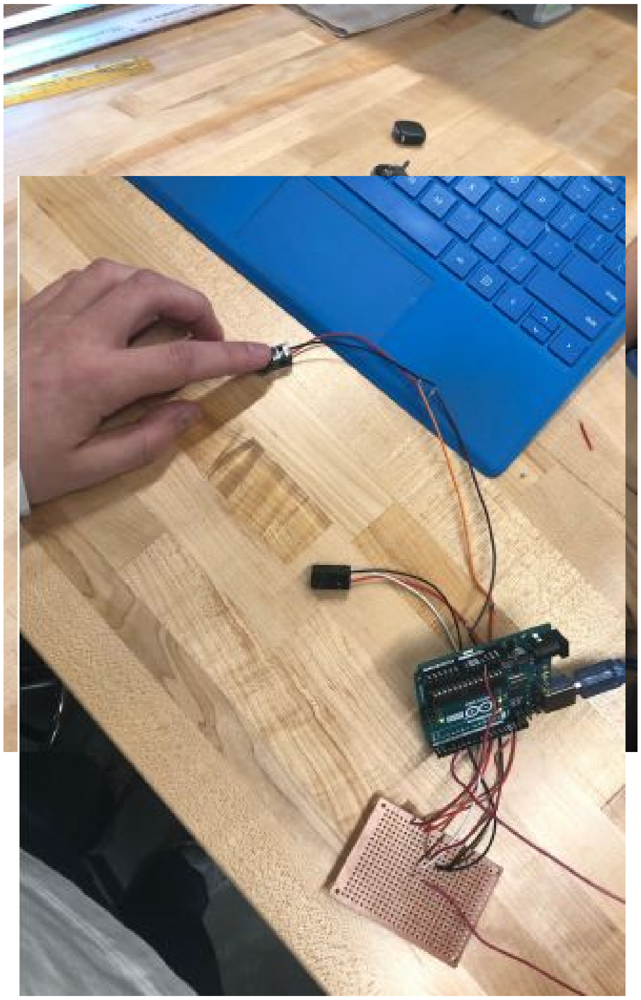
3) Design Brackets to hold the Hopper walls and filter together
4) 3D Print Brackets
5) Acquire sample filter from store
6) Cut filter to proper dimensions
7) Construct complete Hopper using hot glue to cement the pieces together
8) Use leftover sand acquired for prototype 1 to test the new filtration design's efficiency at filtering out both wet and dry sand.

Stopping Criteria Sensors:

There are 2 main situations that have to be resolved in order to stop testing the sensors. The first is when an object passes through the sensors. This stopping criteria occurs when an object passes through the sensors, registers as "blocked" on the serial monitor, and then immediately prints "empty space". This is a necessary stopping criteria since it shows that an object was deposited in the hopper, yet there is still more space. The second situation would be when an object is deposited in the hopper and the hopper is full. The stopping criteria would be that the sensor would print "Blocked" to the serial monitor, and stays as "Blocked" rather than switch back to "empty space" like in the previous situation. This is a necessary stopping criteria because it shows that the hopper is full and trash needs to be removed. Physical design of the hopper and filter: In order to stop testing the physical design of the hopper, 2 things must occur. The first stopping criteria is that sand, including wet sand, exits the hopper through the filter. This is the main goal of the design. The second stopping criteria is that after the sand is removed, the items and garbage in the hopper stays in the hopper, as it does not pass through the filter. This is important because it would be useless if the filter holes were big enough that the trash and sand passed through the filter and back onto the beach. So, only once it has been explicitly shown that sand is being removed from the hopper, and the trash is staying in, can the testing be finished







6. Prototype 3

6.1 Prototype 3 Objectives

The objective of our third prototype was to create a final physical and comprehensive model, by combining the focused aspect of our break beam lasers, with the new hopper/filter and the ramps and columns.

Our hopper/filter system was tested extensively in our first and second prototypes, which meant that we now had to put together our assembly and test it as one final design. In addition to creating a final design, the objective of this prototype was to implement some small design tweaks, that were based off the feedback and concerns that Erin had raised after our short pitch Presentation.

6.2 Client Feedback

Through our feedback with Erin, the client, we learned and implemented three things. The first thing is to ensure a time delay mechanism in the laser program to ensure the hopper is truly full when it receives the blocked message. In the focused prototype of the lasers, we foreshadowed this and made the time delay 5 seconds. However, in order to satisfy Erin’s concerns we increased the time delay to 10 seconds so that the blocked message is guaranteed and a passing can si not misinterpreted. The second piece of feedback that we received from Erin was to rigorously test the filter, in order to guarantee that small objects do not pass through the filter. We took this feedback seriously, because it is paramount that the filter works as intended or else it ruins the whole point of a new hopper system for Bowie. Through testing and benchmarking, we decided to reduce the size of the squares in the filter by .2mm to make the filter 1cm by 1cm, while reducing the height of the filter to .5cm. We determined that this size was an ideal balance between filtering dry sand and wet sand, while also ensuring that small objects are not able to fall through the holes of the filter. The last piece of feedback we received from Erin was related to the elevation of the ramps. One of her concerns was the height in which the hopper would be raised, because this would affect the center of mass of Bowie, and it would be necessary to increase the length of the scooper to account for this increased height. Previously, we determined that the critical angle of the ramps was between 25 and 30 degrees. This critical angle was based upon ensuring that wet sand would not get stuck on the ramp, rather than slide down. Factoring in her concerns, we made the angle of the ramps

25 degrees, on the low end scale where we determined it needed to be. This led to an increased height of the hopper by 10 cm. Since the ramp filter system is the backbone of our design, we felt the effects of the new height would be negligible and worth the small inconvenience of extending the scooper, since it frees up more space inside the hopper and it will allow Bowie to collect more garbage and better perform his task.

We also received positive feedback from Erin. Firstly, she enjoyed the ideas of lasers, provided that they work properly. This is because the lasers vastly improve the user experience, by detecting when the hopper is full as opposed to the user guessing. Another positive aspect of the feedback that we received from Erin was about the filtration system, provided that it works properly and doesn't let any trash through the filters. The reason for this, is that we showed that the filter is able to filter wet sand out of the hopper. Many filtering systems struggle with wet sand, which our system is easily able to filter out. This received positive reviews, since it tackles a significant issue that has hindered Robot Missions goals.

6.3 Critical subsystems

Lasers

The critical function of the lasers are to notify the user that the hopper is full and that there is a blockage between the lid and the space underneath. In the previous prototype, we simply only designed, wired and implemented the code for the lasers. In order to cover the most amount of area inside the hopper, we decided to place the 2 laser systems on diagonals from opposite corners since this allowed for the most amount of area within the hopper to be in the lasers pathway (see pictures below for location of lasers). We had to orient them this way because the lasers are effective up until approximately 25 cm, whereas the hopper length is 30 cm. After the implementation, there were 3 specific ways that were important to test and analyze in order to make sure the lasers are working as we intended. The first of these methods was when the hopper is empty, or not filled up until the height of the lasers. Through our testing, both lasers in fact worked as intended, since they both printed “empty space” to the serial monitor in the situation described. The next situation was when the hopper is full. This occurs when either laser is blocked for more than 10 seconds. After 10 seconds of blocked lasers, “blocked” is printed to the serial monitor of one of the lasers. In the situation that one laser is “blocked” and one has “empty space”, that is up for the interpretation of Robot Missions on how to handle it as this signifies that the hopper is almost full, yet it still has room. The last situation is when an object passes through the lasers but does not block the lasers. In order to differentiate from step 2, 10 seconds after the object clears the lasers “Blocked” is printed to signify an object passing through followed immediately by “empty space” to signify that the object cleared and there is still room.

Filter

The critical function of the filter is to ensure that sand, specifically wet sand, falls through the filter holes, without letting any of the small trash pass through. In order to ensure that this is the case, we tested many different filter designs, by tweaking the dimensions of the holes, along with the type of filter. Ultimately, we determined that a filter with holes of 1cm by 1cm would be the best type of filter, since it allows the most sand, specifically wet sand, to filter through, while maintaining the trash in the filter. This benefit of the filter that we chose, unlike other designs, is that it is able to filter wet sand. We felt like this was a significant issue for Robot Missions, as it is generally hard to dispose of the wet sand because it gets stuck onto trash inside the hopper. However, when we accounted for the vibrations of the hopper as Bowie moves around, the wet sand detaches from the trash and is able to fall through the filter with no issue.Obviously, it was also found that there was no issue with dry sand, and it would fall right through the filter as intended. One concern regarding our filter is that small objects such as cigarette butts would theoretically be able to fall through the holes and back onto the sand. However, through testing we determined that this occurred on extremely rare occasions because it would have to fall perfectly vertical without anything impeding it. Given that there is trash in the filter and sand on the object, it is extremely rare that it would fall directly through on a 90 angle. In many situations, there is lots of trash in the filter which would not allow the cigarette butt from even reaching the bottom of the hopper. With this said, this does not account for the effect of sand on the cigarette butt, which would further deter it from falling straight through. As a result, we were able to determine that the filter is able to successfully filter the necessary trash from the hopper, while maintaining the trash in the hopper.

Ramps

The critical function of the ramps are to ensure that the sand and dirt that is filtered through the hopper is disposed of through the sides and away from the circuits and other important components of Bowie. In order to verify that the design is working, we tested the ramp with dry and wet sand, as this is the type of sand that Bowie will encounter. When using dry sand, the filtered sand slid off the ramps as intended. When using wet sand, the filtered sand also slid off the ramp as intended. Through our analysis, we determined that this occurs so smoothly for the following reasons. When the sand falls through the filter, the force of gravity allows it to generate enough speed so the shift in angle from falling straight down to the ramps does not affect it enough to block it from flowing. Also, the 3D printed PLA plastic of the ramps is a smooth surface with coefficient of static and kinetic friction of approximately .16 and .10, respectively. The smoothness of this surface ensures that the sand does not get stuck to it. In our first prototype testing, we determined that there was often a buildup of sand in the middle of the filter, since the holes were blocked by the ramps. In order to overcome that issue in our design, we made sure to align the ramps with the center of the filter, so that there would be no build up. Through testing, we verified that this works, and we were able to overcome an issue with the ramps that we dealt with in the first prototype.

6.4 Results

Filter

The metric for our design is the percentage of sand that is filtered from the hopper. As we were creating our original design criteria, we had created our ideal and acceptable target specification as 75 and 50 percent, respectively, of sand being filtered from the hopper. Through our testing and benchmarking, we determined that we had hit our ideal target specification, as 75% of the sand is being filtered. Although this is what we had hoped for, the reason that we did not surpass the ideal specification is based on 2 factors that are out of our control. The first is that often times when there are many objects in the hopper, wet sand would sometimes stick to the trash, as the hopper got more and more full. Also, as the hopper filled up, sometimes there was no where for the sand to go, as it was being blocked from reaching the filter. This sometimes led to sand not exiting the hopper as planned.

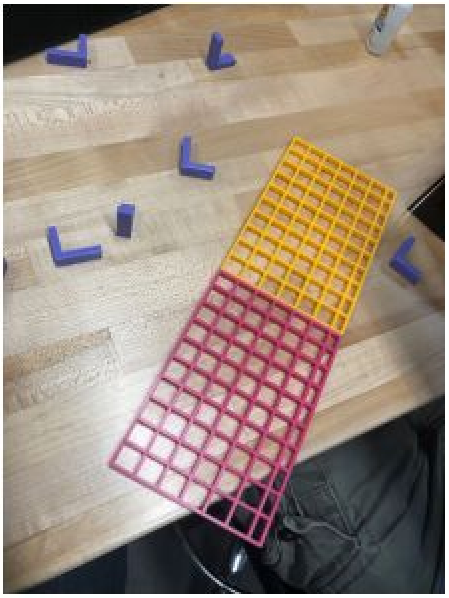
Lasers

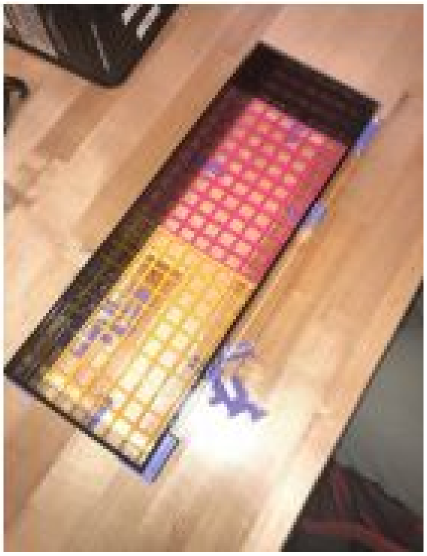
The lasers performed as intended as they always printed the necessary messages to the serial monitor, for each situation that arises, letting the user know if the hopper is empty, or full.

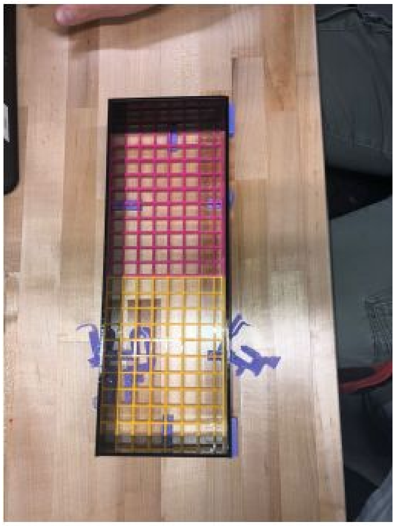
Ramps

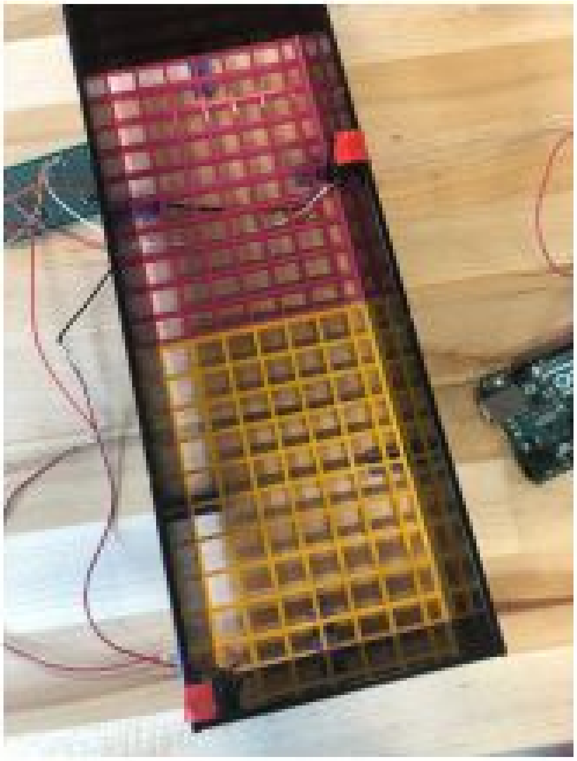
The ramps worked as intended, as they always disposed the sand. Through our extensive testing, we did not arrive at a situation where the sand would filter through the hopper, yet got stuck on the ramps

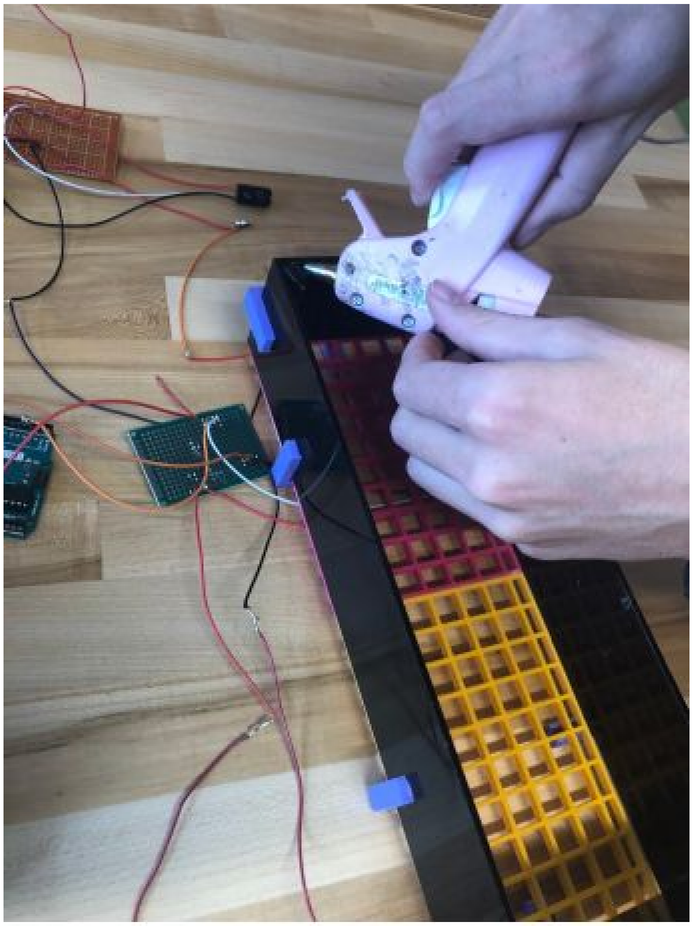
We decided that this prototype would be our final design because we had time restrictions as well as budgetary restrictions since some of our components were fairly expensive like the lasers. We are confident that it solved our problem and hope that there can be many adaptations in the future.











7. Modeling

(CAD, InkScape, Cardboard)

In the case of our hopper walls, we used basic rectangles. This left our team with the decision to either 3D print or laser cut them. Because 3D printing a large geometric shape is very inefficient and unnecessary, we chose the path of laser cut acrylic. This was done using the vectoring software InkScape. While straightforward, there was still some general techniques to understand to effectively laser cut. With this software we created rectangles that matched our desired dimensions. Next we adjusted the color and the cutting plane per required laser cutting best practices. This relatively simple tool yielded us our hopper in a significantly shorter period of time than if we had 3D printed it.

The rest of our design was largely 3D printed. For this, we used a design software known as Autodesk Inventor Professional. Some of the parts that were produced with this software are: the filter, the ramps, the columns, and the brackets. The filter was the hardest to design as it was time consuming to find the correct measurements as well as draw the separate physical dividers at equal distances.

The autodesk designs that we had were shared through a common access point; A360. This allowed everyone access to the inventor files, as well as the STL and the Gcode. Since CAD modelling is fairly independent, we assigned specific tasks to different members based on their comfort levels with CAD software.

In the future, I would have liked to incorporate special joiners for the different parts, so that nothing is permanent and specific components can be replaced. An example of this would be dovetails, which would allow us to remove/insert different filters, as well change the angle of the ramps. I also discovered an interesting feature that comes with Autodesk Inventor Professional; the stress analysis. This was used once to analyse the force/weight of the trash on the filter to see what it could withstand. The stress analysis allowed us to select the location/type of force as well as the material of the filter.

8. Conclusion and recommendation

While our team was successful in the fulfilling of our design criteria, we can see where future renditions can improve on our current designs. A major component that can be improved upon in the future editions of our design is the ability of our hopper to integrate with Bowie. Having a system where the hopper could “snap into” place on the robot would be a major increase to the effectiveness of our design. We believe that introducing a filter module where different filters can be easily attached would better the filtering mechanism. A system where the filter can be removed and replaced would allow the operator to adjust based on the filtering needs. Our prototype could also be improved by creating a housing for our sensors. The current implementation of lasers is in its enfant stage and by developing a protective housing they would be allowed to better operate. Other improvement measures include weight saving measures, decreasing the dimensions of supports as well as decreasing the amount of material in the legs of our hopper system. These future implementations can forward our design and make it more implementable.

9. Bibliography

In order to code the sensors using Arduino, we used the code obtained that came with the purchase of sensors from adafruit.com. The only thing that changed was the message printed to the serial monitor when the sensors were empty or blocked, and we manipulated the code to incorporate a time delay when given a blocked signal.

These sensors can be found and acquired at:

https://learn.adafruit.com/ir-breakbeam-sensors/arduino