**Final Report**: Solenoid Based Braking System

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Table of Contents

[Abstract…………………………………………………………………………………………………………………](#_gjdgxs)…2

[Introduction](#_30j0zll)………………………………………………………………………..……………………………………..2

[Empathize…………………………………………………………………………………………………..……………](#_1fob9te)..3

[Define……………………………………………………………………………………………………………….……](#_3znysh7)...3

[Ideate......................................................................................................................................](#_tyjcwt)3

[Benchmarking Information](#_3dy6vkm)[........................................................................................](#_tyjcwt)3

[Design Concepts](#_1t3h5sf)[......................................................................................................](#_tyjcwt)...4

[Prototypin](#_4d34og8)g.[.............................................................................................................................](#_tyjcwt)4

[Prototype Ⅰ](#_2s8eyo1)[.................................................................................................................](#_tyjcwt).4

[Prototype Ⅱ](#_17dp8vu)[..............................................................................................................](#_tyjcwt)..4

[Prototype Ⅲ](#_3rdcrjn)[..............................................................................................................](#_tyjcwt).5

[Design Solution and Features](#_26in1rg)[..........................................................](#_tyjcwt)...........................5

[Modeling](#_lnxbz9)[..........................................................................................................](#_tyjcwt)6

[Test](#_35nkun2)[......................................................................................................................](#_tyjcwt)..........6

[Conclusion and Recommendations for Future Work](#_1ksv4uv)[.....................................................](#_tyjcwt)6

Bibliography……………………………………………………………………………………………………………...7

[A](#_2jxsxqh)ppendix[......................................................................................................................](#_tyjcwt)..8

**List of Tables**

Table 1 - Benchmarking.[................................................................................................................................](#_tyjcwt) 8

Table 2 - Engineering Design Specs[.............................................................................................................](#_tyjcwt)...9

Table 3 – Design criteria[..........................................................................................................................](#_tyjcwt).....10

**List of Figures**

[Figure 1 - Gantt Chart](#_z337ya)[......................................................................................................................](#_tyjcwt)............[1](#_z337ya)1

[Figure 2 - Prototype 1](#_3j2qqm3)[......................................................................................................................](#_tyjcwt)........... [1](#_3j2qqm3)2

[Figure 3 - Prototype 2](#_1y810tw)[......................................................................](#_tyjcwt)........................................................... [1](#_1y810tw)2

[Figure 4 - Prototype 3......................................................................](#_4i7ojhp)[..........................................................](#_tyjcwt). [1](#_4i7ojhp)3

[Figure 5](#_2xcytpi) [-](#_1ci93xb) [Android App English Version](#_2xcytpi)[..........................................................................................](#_tyjcwt)............. [1](#_2xcytpi)4

[Figure 6 - Android App French Version](#_1ci93xb)[......................................................................](#_tyjcwt)................................. [1](#_1ci93xb)5

# Abstract

This report will briefly communicate the design process which was followed to design and create a solenoid based braking system for Bowie, a robot constructed by Robot Missions for cleaning and preserving the environment.

The project's relevance is discussed in the introduction, explaining the reasoning behind the importance of the system mentioned above; the different criteria the system fulfilled and why our system is unique and helpful.

The rest of the document will be focusing more on the specifics of the design process, including benchmarking, problem statement used throughout the lifetime of the project, and a more thorough discussion of some of the clients and their needs. Additionally, a brief description of the different prototypes are included with a depiction of the finalized design, noting improvements made on each prototype.

Finally, future improvements and corrections are discussed to allow the prototype to be attached to Bowie and to warrant its use in the field.

# Introduction

Bowie the Robot is a titular figurehead in the rising world of environmental robotics. His success today is the foundation of all of his robot predecessors in the coming future. The “Solenoid Braking” initiative’s sole purpose was to spur progress in the right direction by making sure Bowie could continue to work through terrain and technical tribulations alike. By ensuring that Bowie remains safe, and by allowing it to move safely through different terrains, it is ensured that Bowie will execute its job more quickly and effectively, and that Bowie’s progress will be much smoother and more efficient.

To keep Bowie safe, there were a few requirements that were met to satisfy the different clients for this project. In the case of Bowie, there are two main clients for consideration; the people from Robot Missions, and the general population that will hopefully one day get to interact with Bowie on a daily basis. The primary client for communications was Erin Kennedy, the CEO of Robot Missions. With her help, different criteria were established to make a braking system that will be easily accessible by the general population in the future. Its easy and effective assembly makes the preparation and the field testing simple for the people of Robot Missions.

Our team has effectively integrated our different skills in both software and hardware to create the system. It will not only be recreated with ease, while also being low-cost, but will also be controlled with ease through a smartphone app, making it easily accessible by the general population in future public iterations of Bowie.

## Empathize

Up until the meeting with the client, Erin, the main concentrations of the benchmarking and design criteria – for what the project will be based upon – were the seed planting or environmental sensors. During the meeting with Erin, the idea for a braking system came up unexpectedly, and seemed to be the new leading idea for the project group that had the most potential to be useful for Bowie. Since the braking system was not a major focus up until the second meeting with Erin, the benchmarking (Table 1) done for Deliverable C (Design Criteria) could not be used effectively, and the problem statement did not fit for analysing the braking system. The current criteria for a braking system refers to the ability to decelerate Bowie from a distance and is only measured on how quickly the braking can stop the robot.

The client came up with a base set of requirements (Table 2) that was later expanded upon through research and benchmarking of braking systems. The base requirements consisted of having the braking system to be modular (can be removed for repairs), can be replicated easily (3D printed parts and availability of components), lightweight (built within the weight limit), a compact circuit design (be able to fit inside Bowie) with a low power consumption, and a total construction cost of less than $100.

## Define

After meeting with our client for the first time, we began translation of Erin’s needs into design criteria (Table 3) and then came up with a problem statement that summarized the interpreted needs into a short, specific and ‘sexy’ sentence: “There is a need to create an affordable, modular and effective robot that is able to sustain the parks and shorelines while collecting data that will assist us in reducing pollution and any harm to our ecosystems.”

## Ideate

### Benchmarking Information

As a group, we decided that the best option for the variable braking system would be compression based. This was decided based on Deliverable D, where we came up with various designs for variable braking systems when benchmarking different products on the market. In this deliverable, we outlined what steps we would take for each prototyping stage and scheduled the time of each steps accordingly into a Gantt Chart (Figure 1). We also created a contingency plan if something would come up that could potentially affect the schedule. Lastly, we came up with a list of materials that we would probably purchase for prototypes Ⅰ and Ⅱ.

### Design Concepts

Initially, we came up with a variety of systems/concepts that would either work as an emergency braking system or a gradient braking system. These systems or concepts are the following: bicycle brakes, claw, cruise control, anchor, wheel compression system, speed sensor system, gear ratio, harpoon, disk brake, rake, variable speed motor control, nearest object grabber, airplane style wheel retraction, electromagnetic braking, parachute, pizza cutter (skis), parking spike and pressurized air. As prototyping continued, a few of the many unique solutions we were able to ideate would be the brake pad having brush bristles and having Bluetooth capabilities for wireless operation.

Using the selection matrix, like the one used in class, we came up with the list of ideas above, grouped them together, then eliminated and combined certain ones to come up with the result of a wheel compression system. By researching the best mechanisms in which would lower a pad onto the wheel, while producing enough force, we came across a solenoid. The wheel compression system can optimally satisfy the need to gradually apply brakes to the robot and slow it down. It would also be able to stop the robot completely at times of emergency. The main problem with this system is that it could cause damage to Bowie while trying to stop at high speeds. Ultimately, we concluded that this wouldn’t be a problem since Bowie would not travel at high speeds.

## Prototyping

### Prototype Ⅰ

The first prototype (Figure 2) was based off our previous ideation session. To make this prototype as realistic as possible, we created a functioning wheel and braking system. With the original idea being to make the user able to fully understand our idea, the following result was produced. Moreover, the feasibility of the idea could be tested. The success of the first prototype meant that the team could get started on implementing the full system with refined circuits, additional options, and an overall more professional design.

### Prototype Ⅱ

The second prototype (Figure 3) was based off prototype Ⅰ and the feedback we received from our client. We gathered all the flaws and successes in prototype Ⅰ and recreated a more reliable and efficient way to stop Bowie’s wheels. For prototype Ⅱ, we focused primarily on creating a circuit that could be applied to our final prototype and to solidify our understanding of a harmonic braking system. Furthermore, we wanted to continue our idea in creating both a gradient and emergency braking system while having the circuit controlled by an Arduino that we would then program. To involve this plan, our group proposed that the solenoid would have 3 different modes: an emergency brake mode which applies a constant force on the wheel, and two oscillating modes with speeds relative to the desired deceleration.

### Prototype Ⅲ

The third and final prototype (Figure 4) was based off prototype Ⅰ, Ⅱ, the feedback we received from our client and our initial vision. We gathered all the flaws and successes in prototype Ⅰ and Ⅱ and then recreated a more reliable and efficient way to stop Bowie’s wheels. For prototype Ⅲwe came up with the solution of using the exact design of Bowie’s wheels and surrounding attachments, which we 3D printed from the design sent to us by our client. This simulated an identical drive system for Bowie and improved our 3D printing and SolidWorks skills. Furthermore, one of our initial goals was the ability to remotely control the braking system. For this prototype, we created an app that connects to the solenoid via Bluetooth. Essentially, this idea reached out to more users. In conclusion, most of the components which allowed our system to function were created by prototype Ⅱ. This prototype was primarily focused on creating a realistic version of Bowie's drive system, determining the most efficient placement for the braking system and overall, creating a more refined version of the design that will be more user-friendly, supporting Bowie’s initiative of becoming widespread.

Design Solution and Features  
  
 This app accompanies a Bluetooth module compatible with a solenoid based braking system designed for Bowie. The app features consist of three braking modes including, manual, slow harmonic motion, and fast harmonic motion. The three different braking modes are controlled through different buttons on the app (Figure 6,7). The “Manual braking” button, activates the solenoid, which keeps the solenoid activated while the button is held down. This feature is designed for Bowie's emergency situations when Bowie is unresponsive or out of control. The “Slow harmonic braking” button, turns the solenoid on and off at a slow frequency pattern when the button is held down and is aimed towards assisting Bowie's travels downhill. The “Fast harmonic braking” button, turns the solenoid on and off at a fast frequency pattern while the button is pressed and is aimed towards Bowie's travels down steeper hills.

Furthermore, we created Voice Control (Internet connection required), which activates Manual braking when user inputs voice command of "manual". Slow harmonic braking, when user inputs voice command of "slow." Fast harmonic braking, when user inputs voice command of "fast." The braking system will stay activated until the user inputs voice command of "off." To make our project accessible to as many users as possible, we made the app available in English and French.

### Modeling

During our second prototype, we had designed a CAD tray to present the electronic components of our design to Erin in a professional manner instead of loosely showing her scattered components which could lead to a poor aesthetic and confusion. In our final prototype, an enclosure for the solenoid and a brake pad were both modelled in CAD software to be implemented in our design as original parts.

## Test

Our strategy was to analyze our ideas and realistically create what was possible by our team based on our abilities. The testing was used to visualize and simulate the elements of our concept onto Bowie’s design which was its wheel. This was done using a motor rotating a wheel to represent the movement of Bowie’s wheels. Generally, the tests determined the success of our design as a braking system through our ability to brake the wheel. The tests concluded that our design could decelerate Bowie successfully. Additional field tests are advised to test the success of the harmonic braking on steep hills.

Conclusion and Recommendations for Future Work

This project was created with the intention of innovating an intuitive and original idea to improve upon the design of Bowie in a way that would add to its overall functionality and in this case, its safety as well. For future use of the system, and to make it fully functional on the field, there are a few improvements that can or should be made upon the current design.

Most importantly, the current system was made with wrong assumptions regarding the height in between the top of Bowie’s wheels to the strut and tube mounted above it. The current system uses this assumption and is attached to the side of the tube to apply a force on the wheel at an angle. Due to the wrong height, the current solenoid doesn’t descend low enough to reach the wheel. Upon the reconstruction of the design, a longer solenoid or a different attachment angle may need to be reconsidered such that the system could stop or decelerate Bowie in the field once mounted.

Another possible improvement that could be done on Bowie is implementing a brush as a braking medium instead of the rubber. The brush would be safer for Bowie’s wheels and result in more gradual braking as opposed to the immediate braking that results from the rubber.

Lastly, some improvements and corrections are suggested to be done on the app; mainly, some occasional bugs that cause the app to either crash, randomly lose connection, or result in the solenoid being stuck. These problems could be the result of a used Bluetooth module, so using a new module could solve these issues. Fixing the app so that the Bluetooth connection does not disconnect while switching between languages will also be required. Additionally, more languages could be added to the app to make it accessible to a more widespread user base.

Generally, some improvements could be done upon the design itself or the materials used, to make the system more sustainable, compact, and more environmentally friendly.

We hope that the design created will be successfully integrated with Bowie in the future, while taking into consideration the different improvements that might be necessary for the final design.

It is also important to note that in addition to the successful implementation of the prototype, our team has learned many lessons that will be valuable for our personal skills and for future projects or designs that we will participate in. Namely, throughout the entirety of this project, we developed our programming skills and knowledge to create mobile applications, while also getting some practice with the design of user interfaces that are appealing and user-friendly. In addition, we gained some practical skills in SolidWorks and electrical circuits. Through our use of the MakerSpace, we had some practice in 3D printing the modules we designed on SolidWorks and soldering on PCBs. Overall, we learned how to manage a project using the design thinking process. We also learned how to effectively work as a team in the most productive and organized manner possible, overcoming challenges along the way.

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Muriel, M. (1998). Ld-Walker Walk Behind Beach Cleaner Machine. Retrieved February 9, 2018, from https://rainbowgreenhouse.en.made-in-china.com/product/JSOxtnEBjURm/China-Ld-Walker-Walk-Behind-Beach-Cleaner-Machine.html

# APPENDIX

**Benchmarking** (Table 1 – Benchmarking)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Importance**  **(weight) (1-5)** | **Automatic Seed Sowing Robot** | **Solarino Beach Cleaner** | **Ld-walker** |
| **Company** | N/A | Nevon Projects | Dronyx | Rio Beach Cleaner |
| **Cost** | 5 | $497.01 CAD | $27,681.50 CAD | $8807.75 CAD |
| **Weight** | 3 | Not listed | 500 kg | 280 kg |
| **Size** | 2 | 0.45 x 0.4 x 0.4 m | 2.29 x 0.764 x 1.3 m | 2.58 x 0.86 x 1.07 m |
| **Total power consumption** | 4 | Not listed | 4800 W | Not listed |
| **Energy Source** | 3 | Battery | 2 x 200 Ah Sealed AGM Battery | Not listed |
| **Voltage** | 2 | 12 V | 12 V | Not listed |
| **Frame** | 2 | Steel | Stainless steel, aluminum | Steel |
| **Automation** | 5 | Fully Automatic Seed Sowing | Remotely Controlled | Direct gear drive |
| **Noise pollution** | 3 | Not Listed | Silent | Not listed |
| **Wheels** | 4 | Tractor wheels, with pins to allow strong grip with the ground | 2x2 tracks that offer a good grip even over wet sand terrain | High flotation rubber tires |
| **Working speed** | 3 | Not listed | 2.7 km/h | 3.56 km/h |
| **Working Capacity** | 4 | Not listed | 3000 sqm/h | 3200 sqm/h |

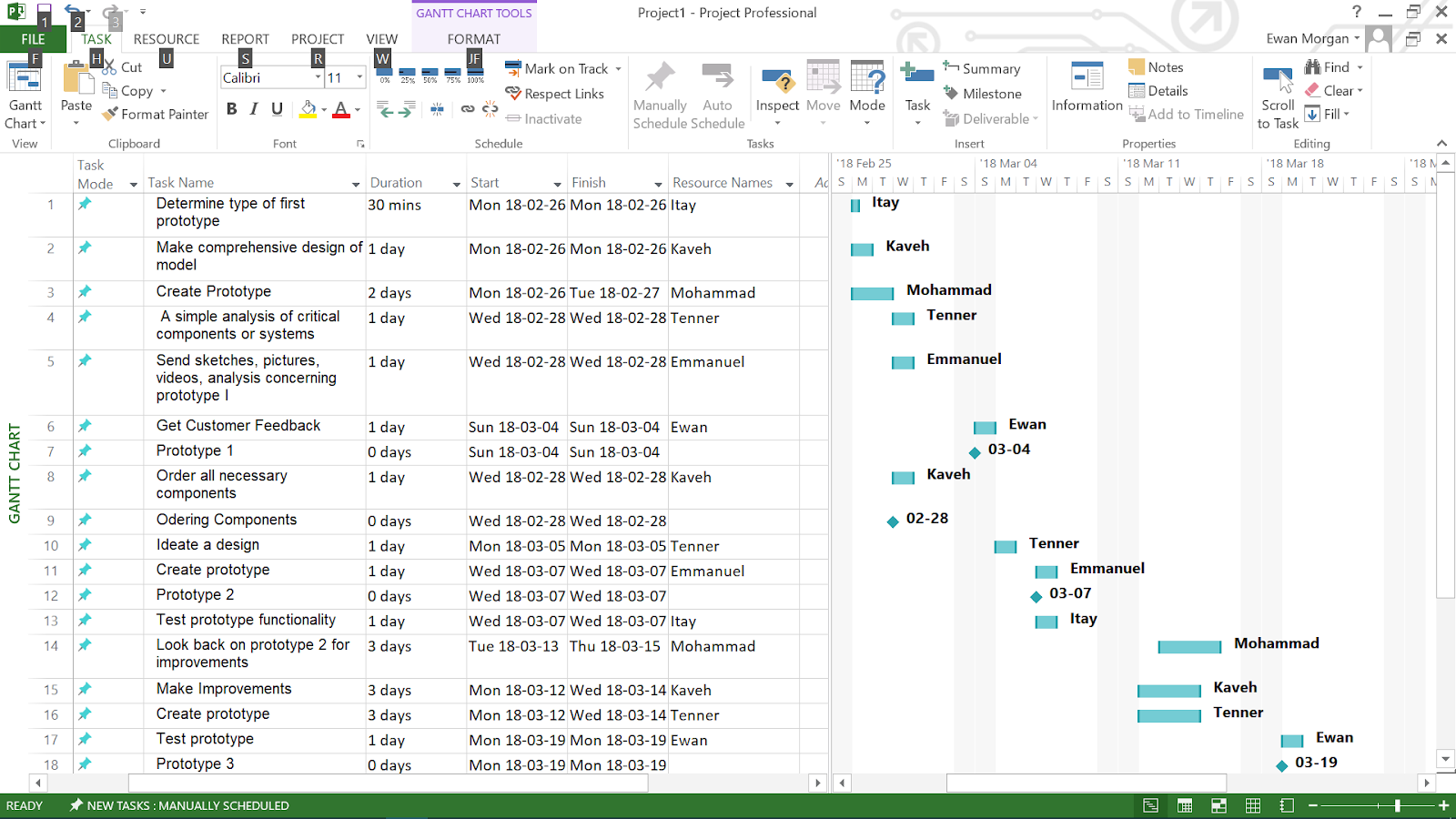
**Engineering Design Specs** (Table 2 - Engineering Design Specs)

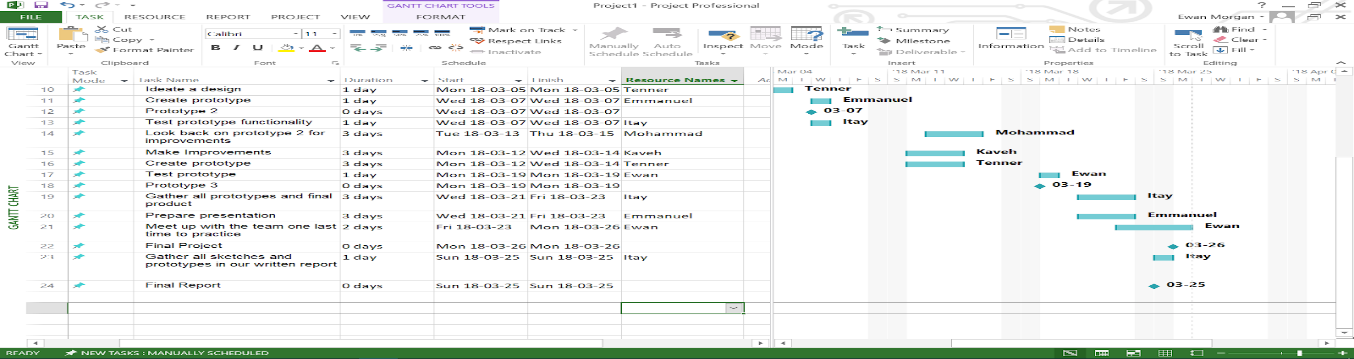
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Design Specifications | Relation (=, < or >) | Value | Units | Verification Method |
| **Functional Requirements** | | | | | |
| 1 | Sampling data abilities | N/A | Yes | N/A | Test |
| 2 | Ability to detect poor soil | = | 5.5 to 7.0 | PH | Test |
| 3 | Attachable water hose | N/A | Yes | N/A | Test |
| 4 | Data logging abilities | N/A | Yes | N/A | Test |
| 5 | User-friendly app to give Bowie different commands | N/A | Yes | N/A | Test |
| 6 | Mesh network | N/A | Yes | N/A | Test |
|  | **Constraints** | | | | |
| 7 | Water resistance | >= | 64 | IP | Test |
| 8 | Better design for wheels and a suspension mechanism | N/A | Yes | N/A | Test |
| 9 | Autonomous | N/A | Yes | N/A | Test |
| 10 | Low powered components | <= | 5 | V | Test |
| 11 | Modular design and 3D printed components | N/A | Yes | N/A | Test |
| 12 | Cheap design | <= | 100 | $ | Estimate, final check |
| 13 | Low noise mechanical parts | <= | 45 | dB | Sound sensor test |
| 14 | Lightweight components (ex: carbon fiber and aluminum) | <= | 3 | kg | Analysis |
| 15 | 3D printed components and contains accessible parts | N/A | Yes | N/A | Optimal amount of 3d printed components |
| **Non-Functional Requirements** | | | | | |
| 16 | Durable modules/components | N/A | Yes | N/A | Do real-time field tests |
| 17 | Safe and user-friendly | N/A | Yes | N/A | Focus groups |
| 18 | Can be remotely stopped | N/A | Yes | N/A | Field Test |

**Translating Needs into Design Criteria** (Table 3 - Design Criteria)

|  |  |  |  |
| --- | --- | --- | --- |
| **#** | **Requirements/constraints** | **Need** | **Design Criteria** |
| 1 | Constraint | The robot can be exposed to water and/or submerged in water | Water resistance |
| 2 | Constraint | The robot can move through difficult terrain like wet sand in particular | Better design for wheels and a suspension mechanism |
| 3 | Non-functional | Robot is durable to the elements | Durable modules/components |
| 4 | Non-functional | Sensors and sampling equipment are durable | Durable modules/components |
| 5 | Functional | The robot is able to sample data (soil moisture, water pH and air quality) | Sampling data abilities |
| 6 | Functional | The robot can deploy seeds throughout parks | Ability to detect poor soil |
| 7 | Functional | The robot can water plants in multiple areas | Attachable water hose |
| 8 | Functional | The robot can collect data to track and observe invasive species | Data logging abilities |
| 9 | Constraint | The robot has interchangeable parts and is easy to dismantle | Modular design and 3D printed components |
| 10 | Non-functional | The robot is engaging for children and safe to use | Safe and user-friendly |
| 11 | Constraint | The robot is quiet when operated | Battery-powered and no heavy and/or loud mechanical parts |
| 12 | Functional | Robot can be easily accessible through automation services | User-friendly app to give Bowie different commands |
| 13 | Functional | The robot is able to communicate to other Bowie robots | Mesh network |
| 14 | Constraint | Robots require minimal supervision | Autonomous |
| 15 | Constraint | Equipment for the robot is lightweight | Lightweight components (ex: carbon fiber and aluminum) |
| 16 | Constraint | Robot uses low-energy consumption | Low powered components |
| 17 | Non-functional | Robot can be deactivated if a critical malfunction occurs | Can be remotely stopped |
| 18 | Constraint | The robot and its components are low cost | Cheap 3D printed components |
| 19 | Constraint | The robot can be easily replicated and fixable | 3D printed components and contains accessible parts |

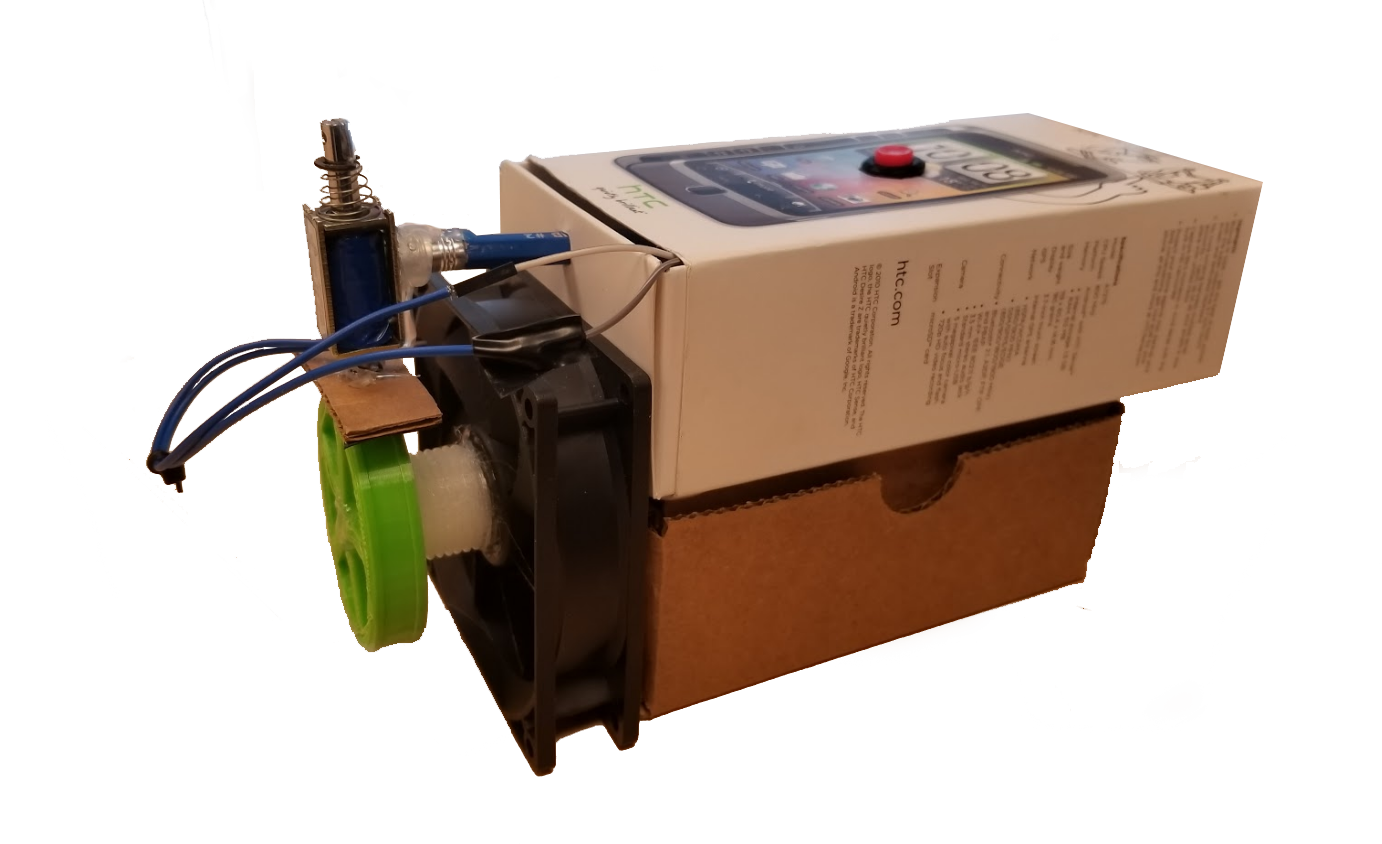
**Gantt Chart**



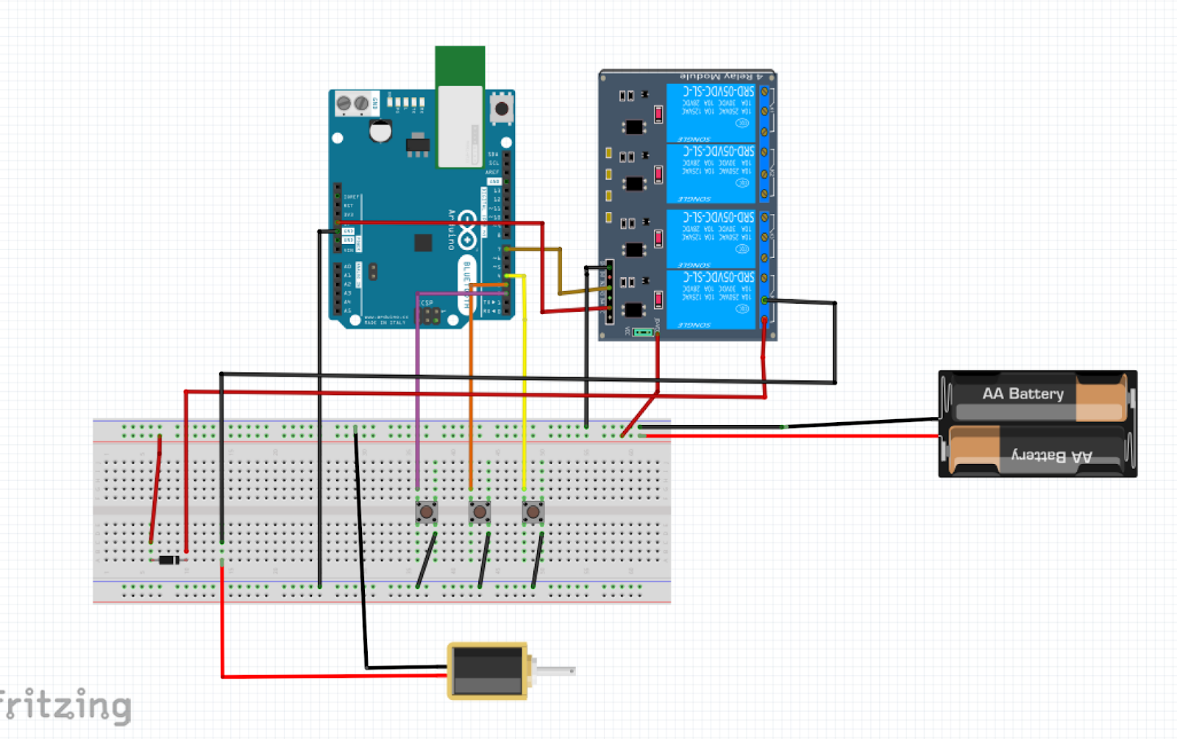


**Figure 1 - Gantt Chart**

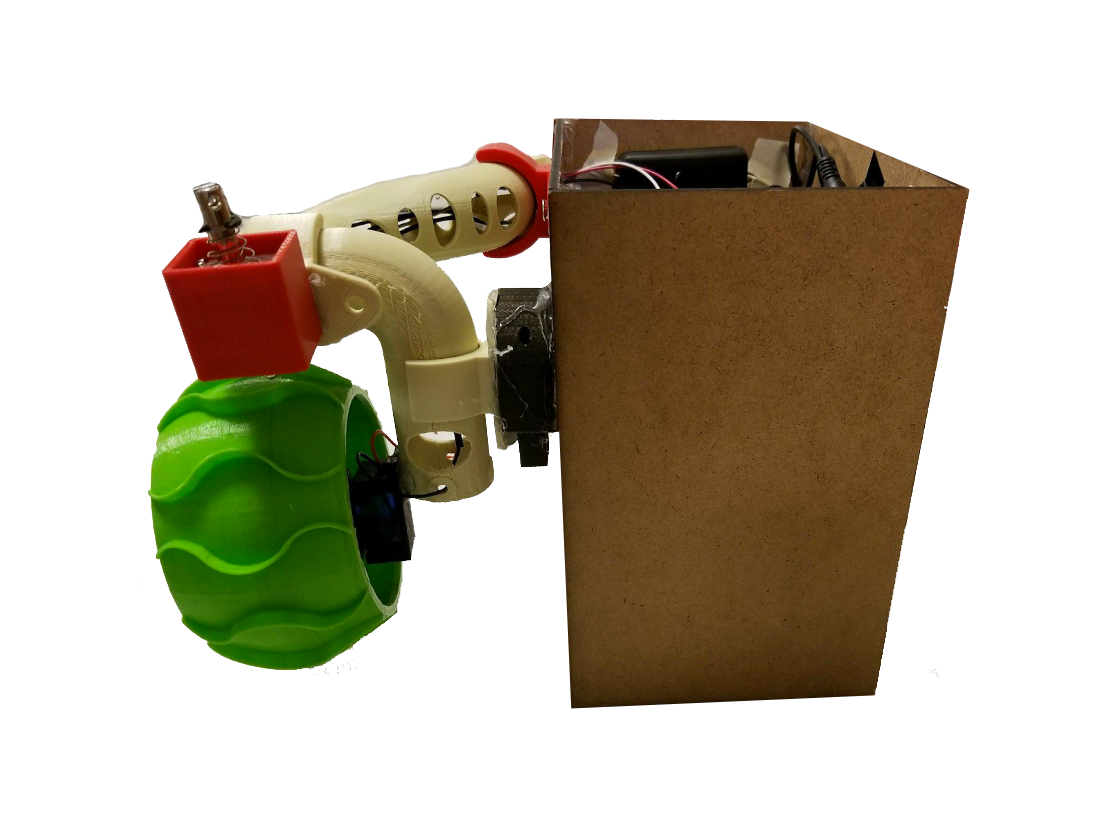
**Prototypes**



**Figure 2 - Prototype 1**

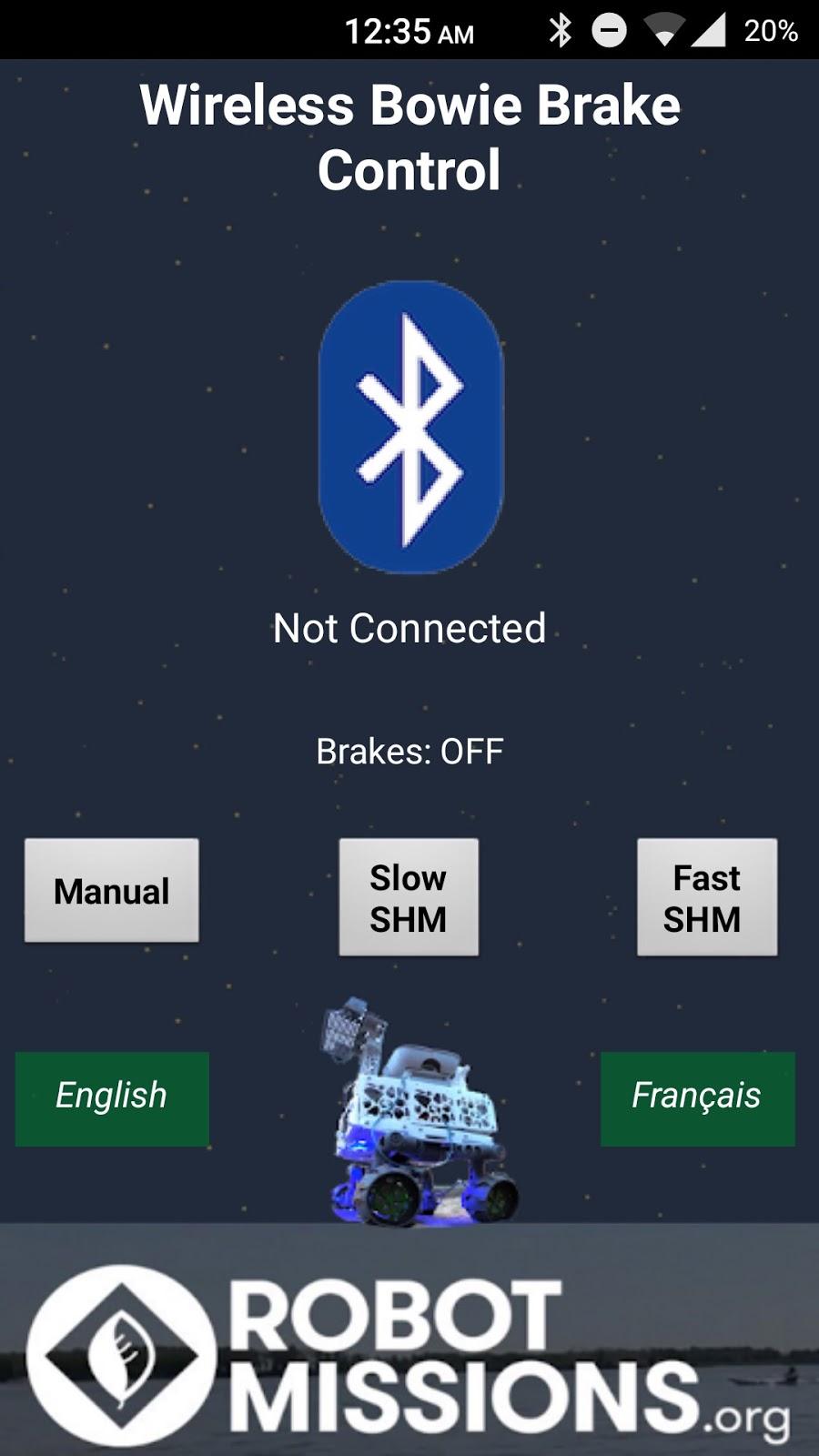


**Figure 3 - Prototype 2**

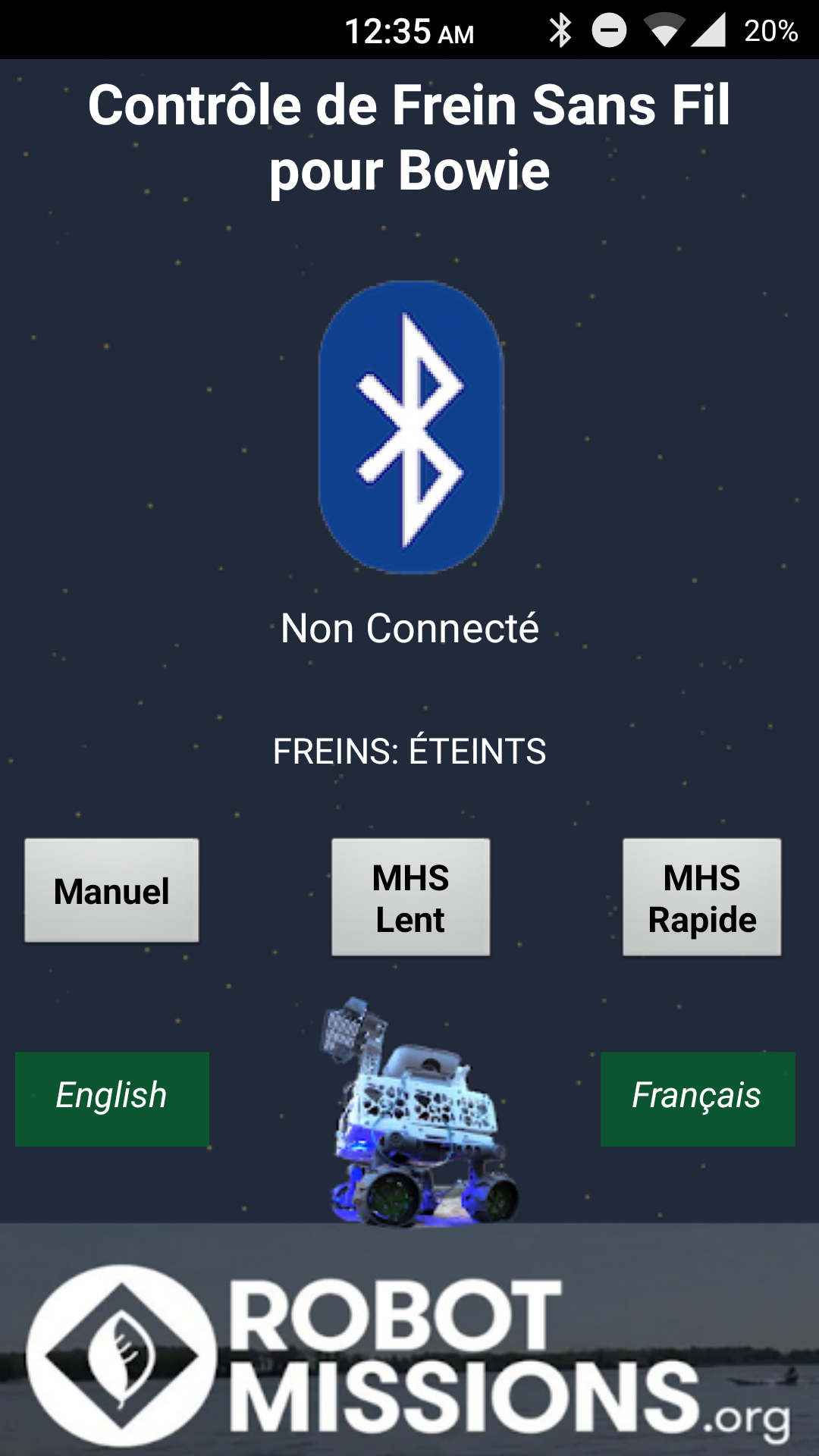


**Figure 4 - Prototype 3**

**Android Application**



**Figure 5 - Android App English Version**



**Figure 6 - Android App French Version**