Albert 2.0

Boston University Department of Mechanical Engineering
ME461 Capstone Experience Section A1
Albert 2.0: Smart Mini-Hovercraft
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Professor Enrique Gutierrez-Wing
Sponsor: Professor Alberto Tron
Final Report

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Abstract

Our team is focused on designing a functioning hovercraft prototype for studying control of non-trivial dynamic systems in a motion capture arena. The prototype should demonstrate increased operation time and less trivial dynamics compared to existing quadrotor drones and RC cars while utilizing sensors for autonomous control and maintaining a durable, manufacturable design. These requirements should be met under the existing constraints of COVID-19, a two-semester time frame, and a budget limit of $500, as well as anticipated technical constraints regarding the integration of autonomous control systems and proper design of a hovercraft system. Our team successfully built and tested two hovercraft prototypes. The first, fondly named "Albert 1.0" demonstrated sufficient lift and propulsion to allow it to move over various surfaces, the successful integration of a RC control system that allows for user control of steering and power for the hovercraft, and had a tested run time of 35 minutes. The final prototype uses ultrasonic sensors for obstacle detection as well as a new body, which improves on its predecessor in its design for manufacturability and increased durability.

Team Introduction

We are Team 11: (left to right) Chuwei Chen, Drue Davis, Charles McRae, Nicolas Lai, and Zahra Marhoon

Drue Davis: Meet our Team Captain, Liaison, Organizer, Dictator and Communicator. Both over Zoom and in-person, Drue helped push our team towards progressing the hovercraft designs by making the proof of concept prototype and traveling to Boston to help film the Albert 1.0 video. Her teammate kindly commented that “there is no Albert without Captain Drue, it would just be a little Alfie (an incomplete Albert)”. All hail Captain Drue!

Zahra Marhoon: The master laser cutter and shopper of our group. Zahra’s passion for design and previous experience with laser cutting provided our hovercrafts with their unique flare. She ensured we had all the materials we needed and more, by offering design solutions like the clear plastic windows on Albert 2.0 as well as the construction of Albert 1.0’s foam body. In her spare time, Zahra enjoys shopping and taking photos and is quite the skilled seamstress creating her own clothing as well as halloween costumes.

Nicolas Lai: Nick is the spirit of our team, coming to us from Oakland, California. Nick is never one to say no to a challenge. His previous experience building a quadcopter provided excellent insight into the development of our project. His distance from the team in Boston drove him to design his own model using Carbon Fiber. Nick also likes to run his dog Summer and works a minimum of six jobs at a time.

Charles McRae: Meet our mechanical design and CAD specialist. Charlie spends his time hiking, running, rock climbing, skiing, and becoming one with nature. His CAD skills really helped make the model of Albert 2.0 come to life. Charlie's eye for design was crucial in the development of both prototypes and made him an excellent addition to our team. Charlie will not go a day without running an olympic marathon and winning the gold medal….Every. Single. Day.

Chuwei Chen: Coming from China to the US, Chuwei is obtaining a major in Mechanical Engineering and a minor in Computer Engineering at BU. With his great passion in both fields, he firmly chose this project that would allow him to apply most of his skill sets. Chuwei's affection for Albert is like that of his child and he put a great deal of effort into the project. Chuwei was the project's leading software engineer, and following graduation he will pursue a master degree in Electrical and Computer Engineering at BU. In spare time, Chuwei loves snowboarding, playing guitar, and enjoying R&B music whenever he can.

Executive Summary

Albert 2.0 is a smart mini-hovercraft. It has the capability to traverse any non-porous surface and is controlled via RC controller. *Albert 2.0* also features ultrasonic sensors for autonomous obstacle avoidance capabilities. This feature alerts drivers when approaching obstacles and allows *Albert 2.0* to come to a sudden stop when obstacles are in a specified range. With its durable design, *Albert 2.0* can be used to study vehicle dynamics in hazardous environments, act as a proxy for space vehicles, and used to test control algorithms in a motion capture arena.

Over the course of this project our team was able to design and manufacture three functioning prototypes despite the restrictions of COVID-19. We started this project with a proof-of-concept design that used cardboard, trash bags, and a CPU fan to demonstrate how our project would be able to successfully hover. This led to the creation of a second prototype designed with foam board and a plastic bag. This model was capable of sustaining enough air pressure to provide lift as well as necessary propulsion to drive the craft over flat surfaces. Taking our findings from these models, we were able to construct a more sophisticated hovercraft called *Albert 1.0* that incorporated an RC control system. This prototype was a huge success whose results led to the final realization of our project, *Albert 2.0*.

This document further details the Smart Mini-Hovercraft Project proposed by Professor Roberto Tron and the benchmarking research that describes the advantages of automated miniature hovercrafts. In addition, it outlines the strategies our team used to design a functioning

prototype that satisfied the client's design criteria, and provides a detailed timeline of the design process and our accomplishments. Included in this document is our principle feasibility study as well as the findings from our first hovercraft prototype *Albert 1.0*. Furthermore, this document presents our final prototype *Albert 2.0* designed based on the results and conclusions from our initial testing. Lastly, this report details *Albert 2.0's* production cost, and provides final recommendations for future work.

Acknowledgements

Our team would like to formally thank all of the people who aided in the completion of this project. Starting with the project sponsor, we would like to thank Professor Roberto Tron for proposing such an amazing project. Not only did he aid in our design decisions, but he also provided us with previous work on this project that aided in our initial design process. We would also like to thank Professor Hauser for supporting our hot cocoa delivery idea and providing us with critical feedback that allowed us to further improve our prototypes. Finally, we would like to express our deep gratitude to Professor Enrique Gutierrez-Wing. He has aided this project every step of the way and has also provided essential feedback to our group. Most importantly, Professor Gutierrez inspired us to keep pushing forward and his continual support motivated us to reach beyond our initial design goals. All of these people are largely responsible for the success of our team. Not only did they teach us more about engineering, but they gave our group the opportunity to truly enjoy the entire design process of *Albert 2.0*.

Project Overview

Project Description

The *Albert 2.0* prototype is an exciting smart mini-hovercraft that demonstrates the combined dynamics of ground and aerial vehicles and is equipped with obstacle avoidance capabilities. Designed for durability, *Albert 2.0* uses 3D printed motor mounts and balsa wood for its main structure allowing for a clean and lightweight design. The hovercraft skirt is made from ripstop nylon, a light-weight fabric reinforced to minimize the effects of wear and tear, which aids in creating a sufficient air cushion beneath the vehicle and enables it to better travel over rough surfaces. Equipped with three ultrasonic sensors, *Albert 2.0* is able to detect obstacles up to 4 meters away. The hovercraft is programmed to alert drivers of oncoming obstacles by means of LED lights. Capable of travelling at high speeds, the system is designed to reduce its speed and even come to a complete stop when obstacles are within 0.2 - 0.4 meter range.

Albert 2.0 will serve as a platform for studying the control of systems with non-trivial dynamics within a motion capture arena in the BU Robotics Lab It will also be used as a proxy for space vehicles for testing control algorithms in various settings. The *Albert 2.0* hovercraft was designed to provide a suitable alternative to existing miniature vehicles to increase its ability to aid in laboratory and research environments. Compared to quadrotors and RC cars, *Albert 2.0* demonstrates increased operation time, capable of hovering for over 45 minutes. In addition, *Albert 2.0* provides a happy medium between typical ground and aerial vehicles. Hovercrafts are able to reach more sophisticated dynamics while maintaining a simplistic design and can easily travel over non-porous surfaces giving it increased access to remote or hazardous environments.

The Smart Mini-Hovercraft project designed by Professor Roberto Tron was aimed at successfully developing a working hovercraft prototype that demonstrates increased operation time compared to quadrotor drones, has more complex dynamics than RC cars, and incorporates at least one form of autonomous control. The hovercraft should have a simple, reproducible design that still exhibits sufficient durability for continuous testing in the BU Robotics Lab. In the past this project was taken on by another capstone group, our team was able to learn from the previous project and develop a new design for the hovercraft.

Motivation

Miniature ground and aerial vehicles are evolving into significant tools for research and development. These vehicles can be used to gather environmental surveillance data and simulate vehicle behavior in treacherous environments. However, they are limited by their operation time and dynamics. For example, ground vehicles like RC cars, fail to demonstrate the realistic behavior of motor vehicles because their restricted dynamics render inertial effects almost negligible allowing the car to crash into objects, roll, and clear obstacles with minimal damage. On the other hand, quadrotors are limited by the complexity of their designs due to aerodynamics, and can have short battery life as a result. The most accessible models of these vehicles also rely on continuous user input via remote control.

The benefit of designing a smart mini-hovercraft is that it provides a platform to combine the advantages of both aerial and ground vehicles while also providing a middle ground to balance their disadvantages. Hovercrafts are capable of traversing a wide range of non-porous surfaces with minimal thrust, and achieve non-trivial dynamics with simplistic designs. This is because hovercrafts rely on pressurized air.

By means of a fan, air is forced below the hovercraft causing it to lift off the ground. This reduces friction and allows the hovercraft to glide over surfaces with a simple push or use of a propulsion fan. Thus, hovercrafts demonstrate less complex aerodynamics than aerial vehicles without completely negating the effects of inertial and drag forces.

Another advantage hovercrafts pose is that their operation only relies on three components: a lift and propulsion fan as well as a platform to mount them on. The combination of non-trivial dynamics and straightforward vehicle design makes hovercrafts a viable alternative to miniature aerial and ground vehicles.

Taking it a step further, incorporating on-board sensors for autonomous control provides another advantage to the use of smart mini-hovercrafts. For example, by giving the hovercraft an auto brake system, it would enable the craft to aid the driver in decision making.

Benchmarking Research

RC Cars & Quadrotors

The first step we took before planning our hovercraft was to analyze what products were currently available on the market. Our research showed that there has been much innovation in quadrotor designs over the past few years. As seen in Table 1 below, the company diji designed a compatible hovercraft capable of running for 34 minutes. This quadrotor is also equipped with advanced obstacle avoidance and vision systems that give it some autonomous capabilities, but this also brings the cost of the product up to $800. On the other hand, RC cars have very similar designs across the board. Newer RC car models have been designed to go faster and have more aerodynamic body designs to mimic real vehicles. However, there are not many RC cars available designed with the intention to simulate real-world vehicle behavior or autonomy. The last area we covered in our initial benchmarking research had to do with existing hovercraft designs. We found that there are some sophisticated hovercraft designs on a large scale used mostly for military applications. Unfortunately, there are not many sophisticated models on the miniature vehicle scale. Most mini hovercrafts are made of cheap materials and do not incorporate advanced systems like models of quadrotors.

Table 1: Examples of Smart Mini-Hovercraft Competitors

Image	 [1]	 [2]	 [3]
Company Name	dji	SYMA	Laegendary
Product Name	Mavic Air 2	Q11 RC Hovercraft	1:10 Scale Thunder RC Car
Description	Compactable quadrotor with 34 minute max flight time. Equipped with obstacle avoidance technology and object tracking.	Automatic door system for large buildings. Specifications can be customized as it is an industry level product.	Ready to run out of the box, reaches speeds up to 40mph
Cost (USD)	799	51.90	269.97

Power supply	LiPo 3s	3.7V 380mAh Lithium Battery	LiPo 7.4 5200mAh
Operation Time (min)	34	24	30
Features	Obstacle Avoidance System, GPS, Vision System, Video Transmission System	Low Battery Reminder, Waterproof, Water Sensor, 4-Channel Interference	Waterproof, Programmable ESC

Operating Principle

Following the completion of market research, we dove into the science and technology behind how hovercrafts work.

As much the same way as a helicopter, a hovercraft throws air down underneath itself and it rides along on top. Usually, on a hovercraft, an engine or a motor powers a central fan pointing downward, and one or more other fans pointing backward. The central fan creates the lift, holding the hovercraft above the ground while the other fans propel the hovercraft forward. Meanwhile, a skirt made in either rubber or nylon traps a cushion of air under the craft, providing the hovercraft enough air pressure that allows the hovercraft to hover above the ground.

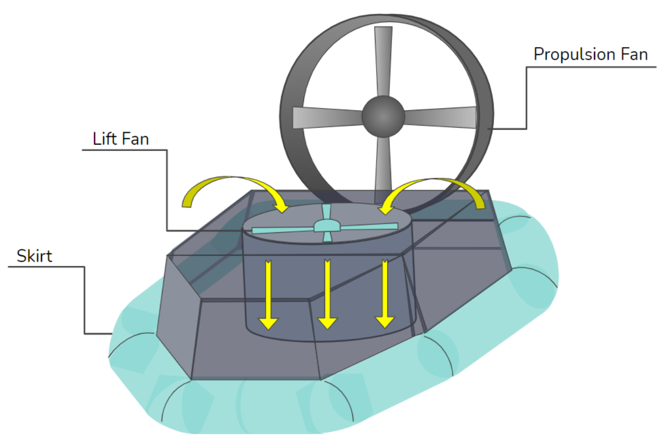


Figure 1: Air Flow Diagram Demonstrating Function of Lift Fan

Concept Selection and Proposed Technology Solution

Design Criteria and Anticipated Constraints

The project proposed by Professor Tron included various design requirements for the final hovercraft prototype. In order to outline our design strategy, we organized these requirements into three sections.

Critical design requirements included designing the hovercraft for manufacturability, incorporating an RC control system, meeting a minimum operation time of 20 mins, capable of supporting a 500g load, and ensuring travel across a 2D plane. Desired criteria covered the integration of more advanced control systems including the use of an onboard computer, camera, and giving the prototype autonomous capabilities in a motion capture arena. The last capability to reach for was the incorporation of onboard sensors for autonomous control. These requirements can be seen in Figure 2.

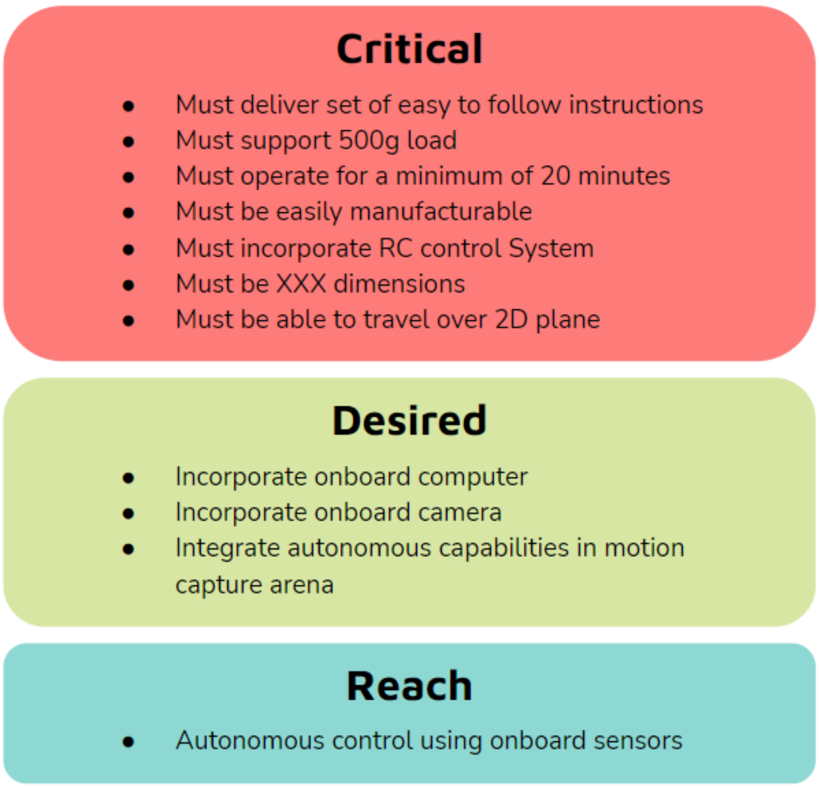


Figure 2: Levels of Importance for Design Criteria

With these goals in mind, we analyzed the potential constraints that accompany hovercraft technology, materials, and scheduling. Although we strived to meet all critical and desired design criteria, our team was unable to integrate autonomous capabilities in Professor Tron's motion capture arena. Therefore, we decided to include onboard sensors for obstacle detection in our design. In conjunction with this, we also considered the constraints associated with the Senior Design course. The primary constraints of the capstone project is a budget limit of $500, $100 per team member. Time constraints include the final project deadline of April 26, 2021 as well as other due dates for presentations and deliverables throughout the span of the course. Another contributor to time constraints that had to be accounted for was delivery time for parts as well as member availability due to living in different time zones. As far as product design, hovercrafts are extremely sensitive to weight distribution, therefore this introduces weight constraints for our chosen parts and materials. In addition, in order for the hovercraft to move efficiently the skirt must be able to properly maintain air pressure without creating too much drag with the floor, as a result a durable, low porosity fabric is needed. Integrating control systems also poses challenges depending on the level of difficulty required to integrate multiple control components like an RC controller, on board camera, or a navigation system.

The most prominent constraint our team had to deal with over the course of this project was COVID-19. Due to COVID-19 restrictions throughout the year, there was limited accessibility to meeting and design spaces. This restricted team meetings to happen exclusively on online platforms like Zoom. In addition, some team members opted for remote learning and were unable to travel to campus to aid in the design phase of the project.

Design Strategy

We decided to approach the design process for this project in a non-traditional manner. way. Rather than thoroughly planning our process beforehand, our group made a proof of concept prototype out of cardboard, trash bags and an old CPU fan. Once we were able to prove we could design a craft capable of hovering we progressed by building off of our models until we reached a final design. The iterations our group produced through the course of this project can be seen in Figure 3. In the endt, we wanted to focus on choosing materials and electronic components that would optimize the performance of our hovercraft. We chose between different types of lift fans and propellers for lift and propulsion. We decided on 2300Kv DC brushless motors. These DC brushless motors are commonly used for drones and have a high performance. We also looked to provide a high storage capacity battery in order to power the motors, we decided on two 1300mAh 45C 3s LiPo batteries.

Accomplishment Timeline

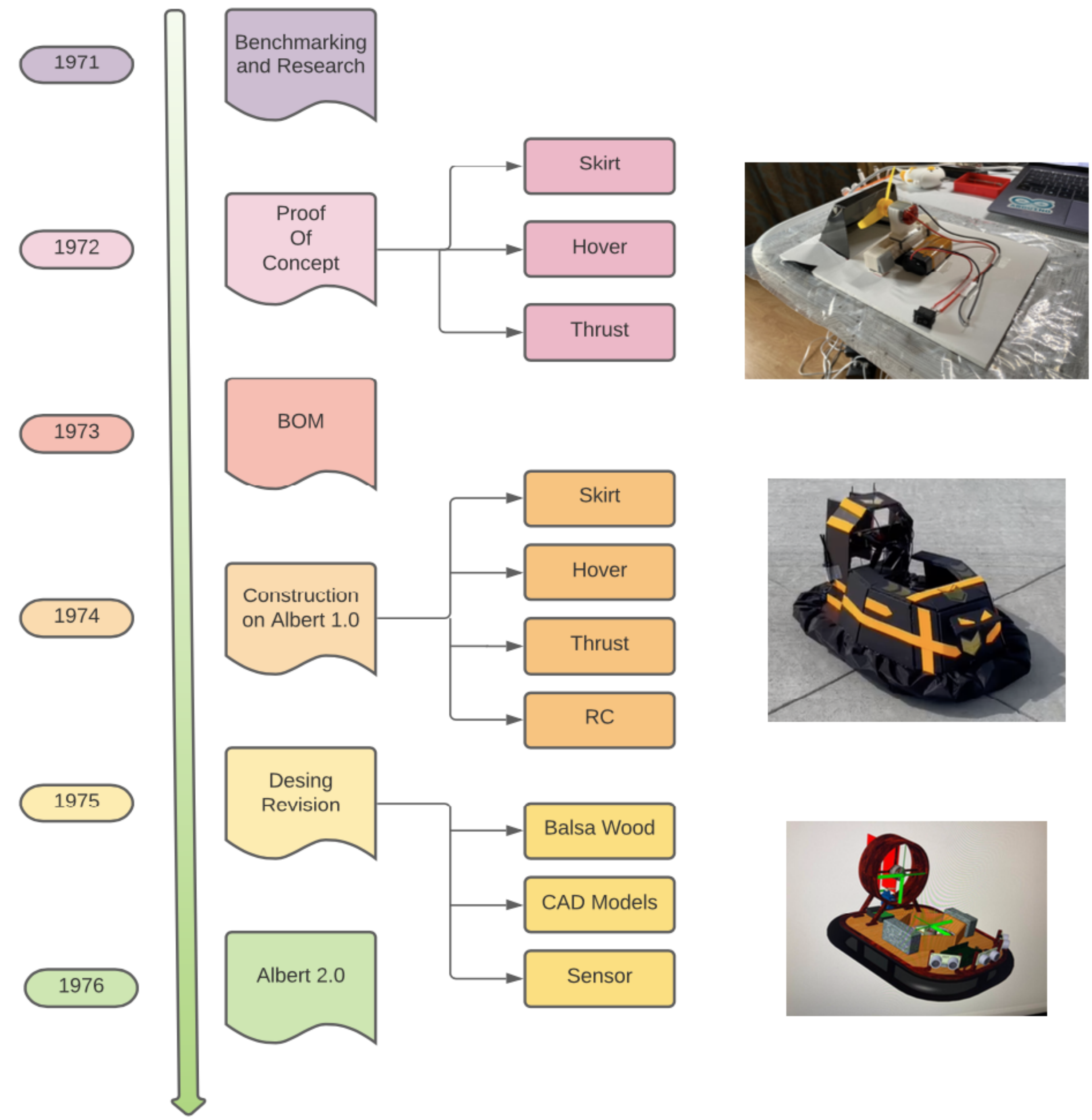


Figure 3: Accomplishment Timeline for Senior Capstone Project

Preliminary Feasibility Study

Statement of Purpose

In order to test multiple hovercraft design concepts, two prototypes were constructed using readily available materials. The overall purpose of these prototypes was to prove the construction of a moving hovercraft was possible. In addition, the significance of designing these prototypes with different features allowed for the observation of the efficiency of multiple design features including skirt design, lift fan, and weight distribution.

Prototype Construction

The first prototype, shown in Figure 4, was constructed using a cardboard body, trash bag skirt, and a CPU fan for lift. The lift fan in this design was centered on the hovercraft body taking up approximately 10cm by 10cm of surface area. The base of the hovercraft had dimensions of 16X14”. The skirt of this prototype was made using a trash bag with two long slits cut into the bottom to allow for airflow.

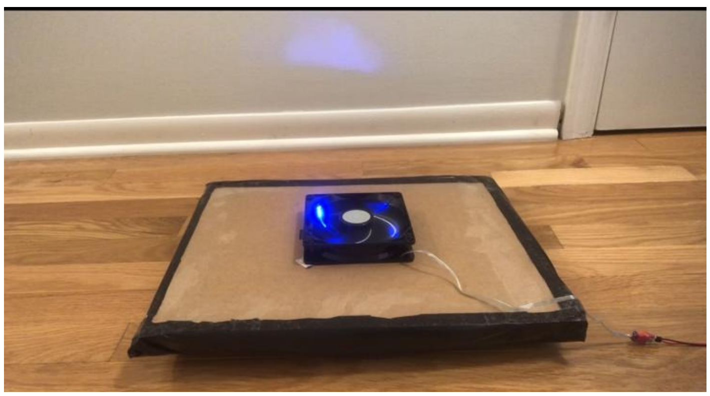


Figure 4: Image of Cardboard Prototype with Centered Lift Fan

The second prototype, depicted in Figure 5, was designed using similar materials, but with a few different key features. The skirt was designed with a light, durable plastic and had a large rectangular cutout at the bottom, commonly referred to as an open plenum design. In addition, a plastic partition was constructed to divide the airflow from a small propeller-driven by a DC motor, allowing the hovercraft to be lifted and propelled by a single motor. The base of the hovercraft had dimensions of 12.8X9’’. In this prototype, a 9V battery is used to power up the motor. The current maximum operating time for the second prototype is around 5 minutes.

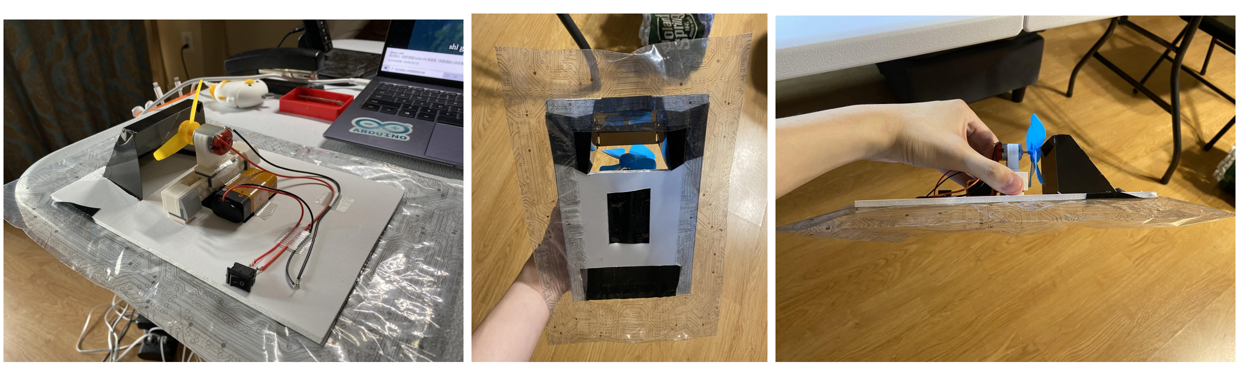


Figure 5: Prototype with Divided Airflow for Lift and Propulsion

Demonstrating Lift:

The initial phase of our prototype testing focused on designing a system capable of maintaining a consistent air cushion under the hovercraft. Passing criteria for successful lift included:

1. Complete inflation of hovercraft skirt
2. Must elevate hovercraft body to achieve zero contact with the ground
3. Reduced friction between skirt and ground
4. Must demonstrate the presence of sufficient air cushion under hovercraft
5. Hovercraft displays ability to travel over smooth plane with minimal outside force
6. Maintain steady air cushion pressure

Must not show any fluctuations in airflow to the skirt, once inflated skirt should maintain the same shape and size over the entire period of testing

Must not show any fluctuations to the air cushion under the craft, once hovering the craft should not experience variations in its ability to travel over a smooth surface (increasing or decreasing friction due to loss of airflow causing the skirt to drag on the floor)

Demonstrating Propulsion:

The second phase of our prototype testing focused on implementing an effective propulsion system capable of moving the hovercraft over a smooth surface. Both prototypes were tested on hardwood floors. Passing criteria for successful propulsion included:

1. Move along a smooth surface
    a. Any translation must be the deliberate result of the propulsion system

Data

Demonstrating Lift:

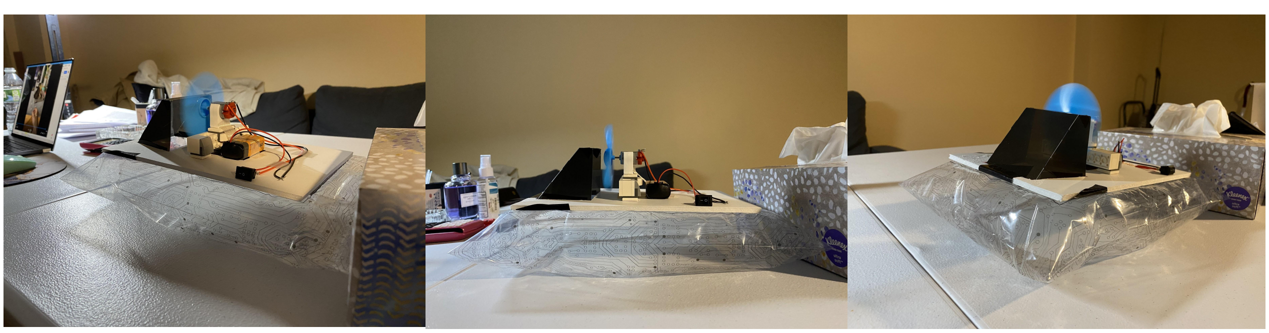


Figure 6: Skirt Inflation of Prototype 2

Both hovercraft prototypes were able to demonstrate a successful lift. The cardboard prototype showed relatively uniform skirt inflation from the start of the testing procedure until the end. In addition, this prototype exhibited reduced friction with the ground as it was able to travel across the floor with a small external push. The cardboard prototype proved the design was capable of maintaining consistent air cushion pressure as the skirt did not lose shape throughout the procedure, and the craft did not experience friction variations while in motion due to loss of air pressure and increased skirt drag. As demonstrated in the video below:

https://drive.google.com/file/d/1MV0vv-RAU76flAO-XrdoeBdr3vERb1um/view?usp=sharing

The divided airflow prototype also demonstrated a successful lift. The lift system was capable of diverting enough airflow to inflate the hovercraft skirt and elevate the body so there was zero contact with the ground. This prototype also demonstrated reduced friction with the ground as it was able to move efficiently across a desk with no external forces. The air cushion pressure was consistent throughout the testing of this prototype as it did not lose air pressure or show difficulty moving as it was tested.

However, in the testing process, we found that the air cushion was sensitive to the overall weight distribution, which means an unbalanced weight distribution would easily squeeze the air cushion, causing instability of the hovercraft. To address this issue, it is necessary to conduct a new comprehensive design that all components on the hovercraft would give a balanced weight distribution, and assign a specific area for the transporting stuff as well. By switching the current motor with a more powerful one might also address the issue to a certain extent.

Demonstrating Propulsion:

Successful demonstration of propulsion was accomplished with the divided airflow prototype. The design of this prototype successfully resulted in the hovercraft being able to move up and down a hallway with no outside interference. Thus proving successful movement of a hovercraft is possible with a simple propeller, DC motor configuration. The demo of the hovercraft's propulsion is in the link below:

https://drive.google.com/file/d/1Ef_53cjU0hzPxd6Y22IQ4cP9MUKDUbiv/view?usp=sharing

The main issue that we encountered for the hovercraft's propulsion was that it can not go straight as shown in the demo. We found the reasons that caused that issue was the unbalanced weight distribution and the not perfectly aligned propeller orientation. Besides, the motor would burn out easily as the hovercraft gets slower after running for a long time.

As for the cardboard prototype, when equipped with a similar propeller, DC motor configuration as seen in the other prototype, the weight, and friction of the cardboard prototype prevented it from being moved entirely. Due to the skirt design, two small channels cut into the bottom, a large surface area of the skirt was in contact with the ground resulting in significant friction. In combination with additional weight from the propeller, the prototype was unable to demonstrate effective propulsion.

Conclusions

Overall, the feasibility demonstration proved a functional hovercraft prototype capable of lift and propulsion can be designed with common supplies. The results and observations taken from these tests provided significant insight into effective hovercraft design. For instance, different skirt designs can decrease a hovercraft's ability to properly move along a surface, as seen with the cardboard and divided flow prototypes. In addition, weight distribution can impact the projected path of the hovercraft, as shown with the diverted airflow prototype.

With the results from the feasibility analysis, moving forward several improvements must be made to the final prototype. The future iterations of the Smart Mini-Hovercraft will address issues such as proper motor selection, incorporating RC controls, improving weight distribution and skirt design, as well as obtaining effective propellers for sufficient lift and propulsion.

Solutions to Power Issues:

Perhaps the simplest of the problems to solve that arose during initial prototype testing is the motor burning out. The motor implemented in the prototype was a relatively weak 6 volt DC motor taken from an inexpensive RC toy set. This motor was sufficient to maintain cushion pressure for a short period of time, however, the motor would burn out very quickly. For further prototypes, more powerful motors and batteries with higher power output and storage capacity will be used.

Brushless DC motors are common in quadcopter drones and are able to spin much faster than regular DC motors. Several motors have been purchased with varying torque output and KV specs and will be tested in the next design iteration. In addition, two three-cell lithium polymer batteries (LiPo), both putting out 11.1 Volts (A standard 9V battery was used in the initial prototype). This will allow for higher RPM motors to be used to lift the anticipated larger loads. The batteries' capacities are 1550 and 2200 mAh respectively. The 2200 mAh battery is significantly heavier than the 1550 mAh version, so results from a battery life test will help to determine whether or not a heavier, higher capacity battery is needed or not. Another consideration is that the final build will likely be heavier than the prototypes, as it needs to hold a payload, be made from materials more robust than household supplies, and carry well-iterated propulsion fans, batteries, and an onboard computer. This places an even greater importance on upgrading the power plant of the craft.

Figure 7: Brushless DC motors. left: 1100 KV Center: 2300 KV. Right: 1400 KV

RC controls:

In addition to the brushless motors and LiPo batteries providing the craft with more power to lift the craft and longer run time, they also lend well to implementing RC controls into the design. Brushless motors have three leads, one meant to go to an ESC (electronic speed controller), which in turn can be relatively easily integrated into an RC system. For the next iteration of the hovercraft, Both the lift and propulsion fans will be radio-controlled, allowing the craft to be moved remotely. The 6 channel RC controller purchased will allow for the integration of servo motors to steer the craft in the channels not occupied by brushless motors, whether it be with a rudder or by rotating propulsion fans.

Figure 8: RC components left to right: 6 Channel Receiver, RC Controller, 30A Brushless Motor ESC

Weight Distribution/Skirt balance:

The prototype hovercraft was designed to move in a straight line, however, in testing it tracked right. There are several possible reasons for this: the weight distribution on the craft creating uneven pressure in the skirt, the propulsion fan not being oriented perfectly straight, and the skirt's symmetry.

While it was found during benchmarking research that weight distribution would play a role in the craft's stability, the feasibility test highlighted that a particular emphasis needs to be made to keep the center of mass of the craft as close to the center as possible. The skirt of the hovercraft maintains even pressure across the bottom surface area of the hovercraft body. It was surmised following the test that the components on the board were not placed in a way that distributed the weight equally from the center. The next prototype will make an effort to remedy this issue.

Another hypothesized key contributor to the craft veering is the orientation of the thrust propeller. Care was taken to mount it straight but even a small deviation from the center axis could have caused the craft to break right. A rudder would help immensely the channel the flow straight.

In addition to the weight distribution of the craft contributing to its tracking right when it was supposed to move straight, the geometry of the outlet of the hovercraft skirt could have been a contributing factor. Ideally, equal amounts of air escape from each location around the skirt perimeter. In other words, the skirt should contribute to lift, not propulsion. However, if the skirt geometry allows more air to escape from one location to the next, this will cause the craft to move in unintended directions. In the next prototype, particular attention will be given to the both design and manufacture of the hovercraft skirt.

Another consideration is whether or not future prototypes will use one fan to both lift the hovercraft and propel the craft. The main reason for using the single fan approach is simplicity and the potential power savings of using one motor as opposed to two. While these may be true, the initial prototype testing highlighted several potential drawbacks. The first is a systemic issue, the craft cannot stay still while maintaining lift. Putting a break in place could solve this problem, but having to install a break would decrease the weight savings of using one motor. Future prototypes will likely feature at least 2 motors, a dedicated motor for propulsion, and a dedicated motor for lift.

Build or Buy propellers tailored to our needs:

Thus far, the prototypes built have been adapting existing propellers, a computer fan, and simple RC toy propellers, to work in a hovercraft platform. Early next semester, a plan has been made to meet with professor Grace to print and test our own purpose-built propellers, or to become familiar enough with propellers designed to make informed purchases of existing propellers and fans.

Albert 1.0

Using information gained from the feasibility analysis we created our first hovercraft prototype *Albert 1.0*. This prototype was constructed with foam board, and used more sophisticated motors for lift and propulsion. By creating this prototype, we were able to meet the majority of our critical design requirements with the exception of a set of instructions and an easily manufacturable design. The results from *Albert 1.0* were critical in developing our final hovercraft *Albert 2.0*.

As seen in Figure 9, *Albert 1.0* was designed very differently from the feasibility prototypes. The new design includes a dual rudder system attached to a servo motor, an RC receiver, an exterior shell and access port. In addition, the prototype uses a support structure for the skirt that cannot be seen in the image. This helps the skirt maintain a uniform shape and air pressure to increase the balance of the hovercraft. *Abert 1.0* was also the first prototype to successfully use an RC controller. This allowed us to test the control of the system and make adjustments to the design to improve handling.

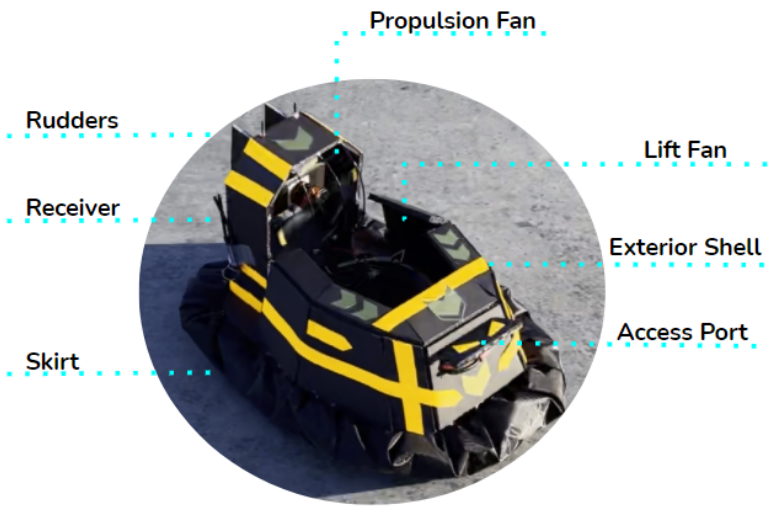


Figure 9: Albert 1.0 Schematic

Functional Decomposition

The functional decomposition of Albert 1.0 shown in Figure 10 provides a visual to better understand the relationship between the various components used in the craft's design. After powering on the system, the lift fan, propulsion fan, and RC control system are activated. Focusing on the RC control system, with the use of two ESCs and a receiver, the speed of the lift and propulsion fans are controlled by the RC controller. The lift fan is connected to the left toggle switch on the controller while the propulsion fan is paired with the right toggle switch. By connecting the fans to the toggle switches, driver's can control the speed of both fans separately. This helps reduce battery usage as the motors do not constantly run at full speed, also it allows drivers to decide if the hovercraft requires more speed or thrust in certain situations. The rudders are also controlled by the RC controller. This provides the driver with full control of the hovercraft's motion.

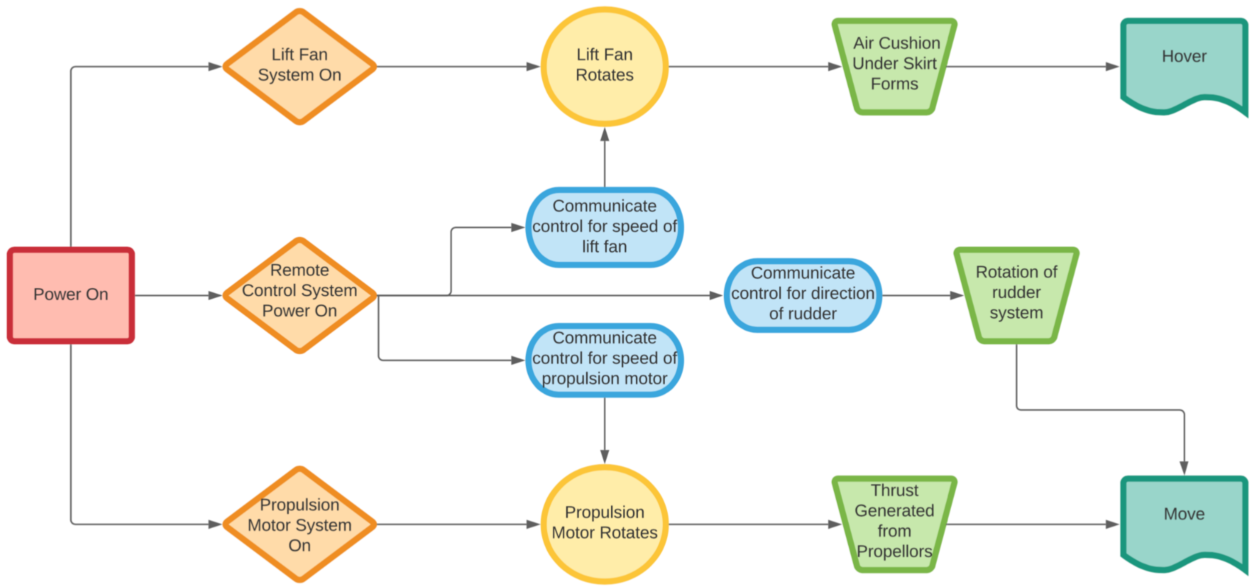


Figure 10: Functional Decomposition for Albert 1.0

Construction

In order to create the body for *Albert 1.0* we used foam board. This material provided the necessary strength to support our electronics, was inexpensive so as not to diminish our budget, and easy to cut into the necessary shapes for our design.

We started construction with the design of the skirt support structure. As seen in Figure 11, this entailed cutting two pieces of foam board. The base, depicted on the left, has four triangular holes cut in its center. This is where the air from the skirt will escape. There are four pillars on the base as well, this holds up the top structure depicted on the right. The top structure has a central hole with a beam across its diameter. This serves as the mount for the lift fan.

Figure 11: Skirt Support Structure Left to Right: Base, Top Structure

Once these two pieces were cut out and the additional features were secured with hot glue, we attached the skirt. Looking at Figure 12, the skirt was cut into two individual pieces. The pieces were then glued to the top and bottom pieces of the support structure before being sealed with a heat sealer along the edges. It is important to note that the underside of the top structure is placed on top of the four pillars and secured with hot glue.

Figure 12: Attaching the Skirt to the Support Structure Before Assembly

Following skirt attachment, the electronic components were placed on the hovercraft. These components included a lift fan, two ESCs, 11.1V Lipo Battery, as well as a servo motor. Another assembly was created to house the propulsion fan and rudders. These items can be seen in Figure 13 below.

Figure 13: Hovercraft Assembly Including Electronics and Propulsion Fan Assembly

In order to make the prototype safe, metal wires were placed around the lift and propulsion fans to form a cage. These ensured no parts would fly off the craft during testing and are depicted in Figure 14. The second safety component we added was the exterior shell. This served to protect the electronics from outside damage as well as to protect us from any exposed wired or heat from the system. The exterior shell was also designed with foam board and cut into panels that were placed along the perimeter of the craft. In the front most pane, an access panel was cut into the board to allow us to easily plug/unplug the lipo battery from the rest of its components. The final model of *Albert 1.0* is shown in Figure 15.

Figure 14: Wire Cages for Propulsion and Lift Fan

Figure 15: Albert 1.0

Results and Key Takeaways

In order to test *Albert 1.0*'s capabilities, we traveled to a nearby skatepark to evaluate the overall performance of his design. Overall the *Albert 1.0* prototype was a success. We were able to properly activate the lift and propulsion fan with the RC controller. The rudder system was effective in driving Albert and demonstrated a quick response time to changes in direction. *Albert 1.0*'s tested operation time was 35 minutes, 15 minutes above our minimum operation time requirement. The video of *Albert 1.0's* test run can be accessed with the link below.

https://drive.google.com/file/d/1_7W_GFs_bdkYShDePx0ggbnxDEI2ZPAR/view?usp=sharing

Additional behavior we noticed while operating Albert 1.0 was the impact of wind on his ability to drive. With strong winds the hovercraft is easily carried away and becomes difficult to handle. This corresponds with the fact that hovercrafts float on an air cushion that reduces friction with the ground. In addition, if Albert 1.0 impacted any obstacles or was blown over by the wind, the lift fan would no longer operate properly. This was due to wires disconnecting due to impact, and enforced the need for secure wire connections in our final prototype. Another critique we made on Albert's performance was improving the connection between the rudders and servo motor in order to increase driving capabilities and handling. Finally, the craft was also observed to lean forward when operating, due to the position of the battery on the craft.

Albert 2.0

The next iteration of our design was called *Albert 2.0*. The main feature of this prototype was the final integration of our collision avoidance, or auto-brake system. Three ultrasonic sensors were arranged at the front of the craft and programmed to shut off the lift fan if the craft approached obstacles within a close range. The benefit of this system is that it allows the hovercraft to determine if something is too close and does not require manual intervention to avoid collisions. The ultrasonic sensor array can be seen in Figure 16.

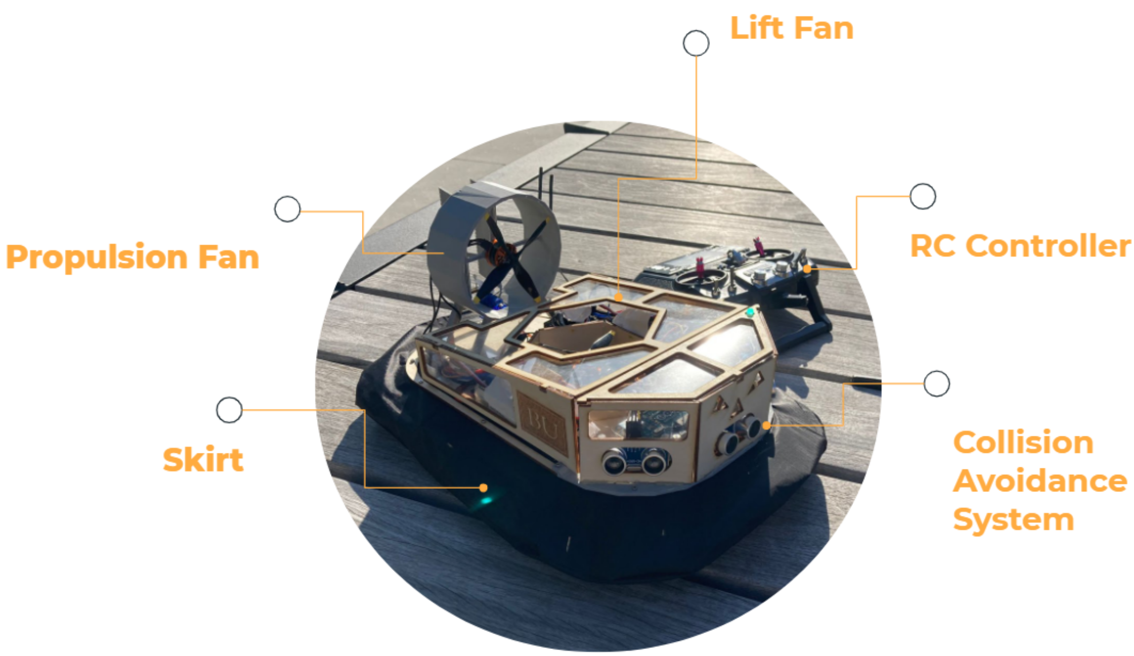


Figure 16: Schematic of Albert 2.0

Functional Decomposition

Figure 17 shows the functional logic of Albert 2.0.

Figure 17: Functional Decomposition for Albert 2.0

Design Overview

Based on our findings from the Albert 1.0 hovercraft, the design for Albert 2.0 made many modifications to the structure of the vehicle. These modifications included use of balsa wood and 3D printed motor mounts over foam board. These changes were made to increase the durability of the craft and to make manufacturing and assembly precise and repeatable.

In addition, as Figure 18 shows, the single 2200 mAh capacity battery was replaced with two 1300 mAh capacity batteries. This had several benefits. First, it increased the overall capacity of the batteries and thus lengthened the craft's runtime In addition, with two batteries placed symmetrically about the crafts center axis remedied the craft's forward tilt due to the weight imbalance the single battery created.

Figure 18: 1300 mAh LiPo Battery

Next, a modular skirt design was implemented to replace the glued skirt on Albert 1.0. This is to allow for an easier changing of skirts should the skirt rip or rupture during operation. This was achieved by clamping the skirt between two rings. The skirt's bottom ring also prevents the skirt from making any direct contact with the ground, mitigating the risk for skirt tears on the bottom surface.

As previously stated, the rear motor mount shown in figure 19 was also redesigned to increase the rudder's responsiveness and increase ease of installation. 3-D printing was selected for this component as it required a complex, precise geometry.

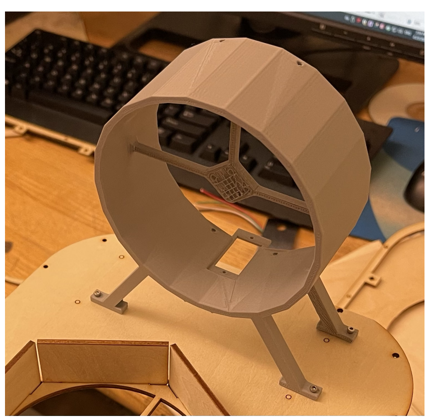


Figure 19: 3-D Printed Motor Mount for Propulsion Fan

The final significant design change to the existing hardware was the replacement of the foam cover with a balsa wood framed, plastic sheet shell. This shell was designed to be partially removable to allow for modifications on the internal electronics. The transparency also allows for viewing inside the craft, which is again useful for repairs as it allows for a user to diagnose electrical problems without fully disassembling the craft.

Circuit Diagram

In addition, Albert 2.0 was equipped with three ultrasonic sensors and an LED to provide obstacle detection capabilities. Figure 20 shows the layout of electronic components on Albert 2.0.

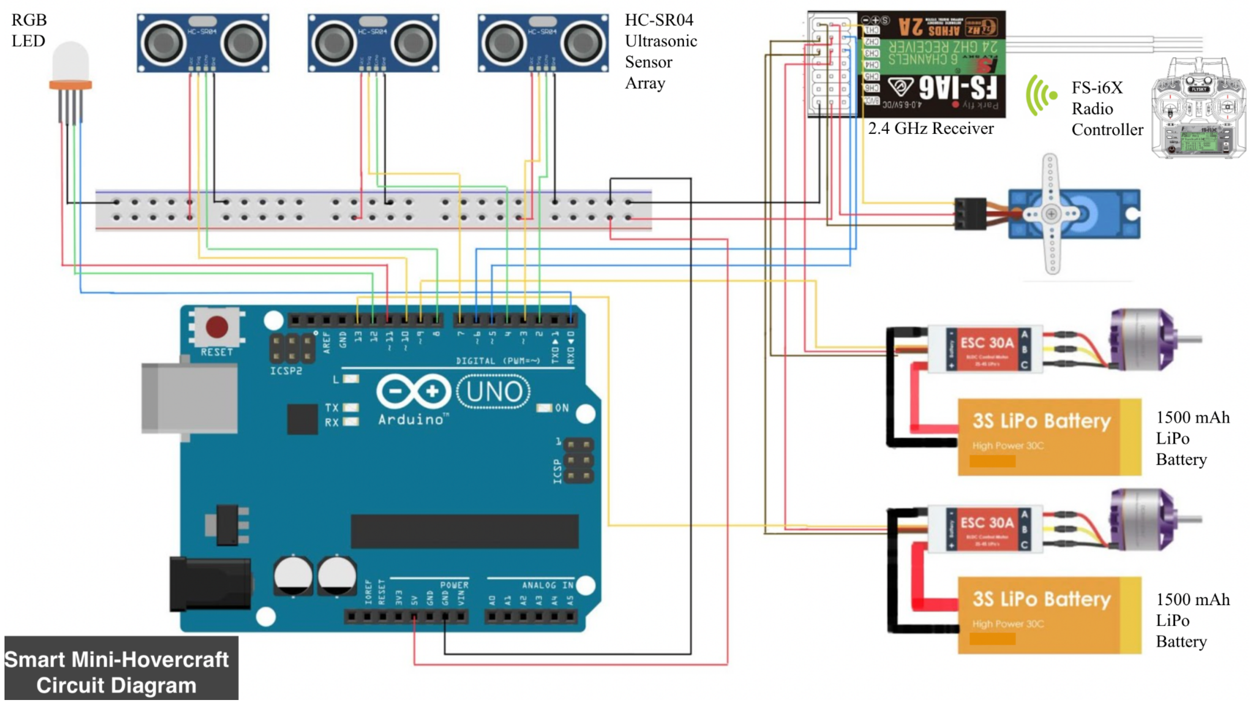


Figure 20: Circuit Diagram of Albert 2.0

Hardware

Platform

The platform is the base that holds all of the components together. It is the body of the hovercraft. In this model we are using a balsa wood platform. We considered using carbon fiber and foam, but when comparing the three materials in Table 2, balsa wood was a better selection.

Table 2: Material Comparison

	Balsa Wood	Carbon Fiber	Foam
Manufacturability	Best	Worst	Good
Cost	Best	Worst	Good
Durability	Good	Best	Worst
Strength	Good	Best	Worst
Weight	Best	Worst	Good

Skirt

The skirt is an important component of the hovercraft, because without the skirt, there is no hover. It has to endure the terrain and maintain the pressure inside of it that creates the air cushion. For the skirt material we decided to use the same material as parachutes, ripstop nylon. This is a lightweight and durable material that can handle harsh weather conditions and is commonly used in aerodynamic situations.

Motor (lift & Propulsion)

When selecting motors for the lift and propulsion we wanted to make sure we had a strong enough motor to meet our needs. At first we thought to use a centrifugal fan for the lift. This idea soon was put to rest when we couldn't find a fan with the right dimensions. We then moved to using brushless motors for both the lift and propulsion. DC brushless motors are commonly used for RC drones and therefore are very appropriate in terms of power, size, and design. The motors in use on this craft are two 2300 kV motors (kV is RPM/volt) and weigh only 24 grams each.

ESC

When using a brushless motor, Electronic Speed Controllers (ESCs) are necessary to regulate the RPM of the motor. They are what communicate the appropriate digital signal to the motors to adjust the speed to how we want it.

Lipo Battery

This design requires a very powerful battery. The brushless motors use up a lot of power and we therefore needed a battery with a lot of storage as well as a high output. Lipo batteries are perfect for small devices such as these homemade projects. With the two 14.8 volts and 1300 mAh LiPo, the battery used was enough to provide about a little over half an hour of life. However, due to the weight of the battery, we moved to using two smaller lipo batteries to supply power to the motors. This allowed for better balance and performance of the hovercraft.

RC Receiver

The FS-i6X is a standard receiver and transmitter used to RC vehicles. It contains a complete controller attached to a transmitter that allows for full control in all directions of the vehicle. The receiver consists of two antennas attached to a box with output pins.

Motor Mounts

To mount the motors in the correct positions in the correct location, we designed 3D models and used 3D printers to print our custom motor mounts. This allows for easy manufacturing of our product.

Propellor (# of blades ~ efficiency)

When selecting our propellers, we kept in mind what we were looking for in our two motors. For the lift fan, we needed more lift which meant more pressure. The higher number of blades you have on the propeller, the less efficiency you get but the more pressure you create. Therefore, for the lift fan, we chose to select a propeller with more blades on it. For the propulsion motor, we were looking for high efficiency and pressure wasn’t a concern. Therefore, we selected a motor with 2 blades which excels in efficiency.

Servo Motors

To control the movement of the rudders, we used a 9g micro servo motor. We do not need to have full revolutions, just minor rotations, and a servo motor is the best for this kind of movement.

Rudder

The rudders are in charge of directing wind in a desired direction so that the hovercraft has turning capabilities. The rudders need to be hard and sturdy so they can direct the wind without faltering. For this we 3D printed our own rudders. This helps with the manufacturability as well as ease in designing the pieces. There are a few different designs we considered. There is a pyramid type or rudder, a single plate rudder, or double plate rudder. We went with the double plate because it was more efficient than the single plate and seemed to have easier control than the pyramid.

Ultrasonic Sensor

The sensor we used for distance measurement was the ultrasonic sensor. The ultrasonic sensor sends out a trigger signal that is then received by the echo device. The time in between is then multiplied by the speed of sound to give a measurement of distance. The ultrasonic sensor has a range of 2cm to 400cm which is more than enough. It also ranges among the cheapest of the distance sensors.

LED

The LED used for this project is an RGB (Red Green Blue) LED. This allows for a single LED to communicate in multiple ways. Rather than having three different LEDs we can just use one. To protect the LED from receiving too much voltage, resistors can be placed in front to protect the LED.

Safety (fans, and outer body)

A safety design we considered in this project is a casing to protect the user from specifically the lift fan propeller from flying off. Aside from the aesthetics, the casing can maintain all the components of the hovercraft within the building of the model.

Construction

Albert 2.0s construction took a very different set of steps compared to its earlier models. Before starting construction, the propulsion fan motor mount, two rudders, as well as a top ring for mounting the ultrasonic sensors had to be 3D printed. Following this, the main body was laser cut from balsa wood. Preceding this, the parts were assembled using nuts and bolts as well as wood glue. The CAD model for this design is shown in Figure 21 below. For more detailed instructions please refer to the Appendix: ***Instructions for Tron***.

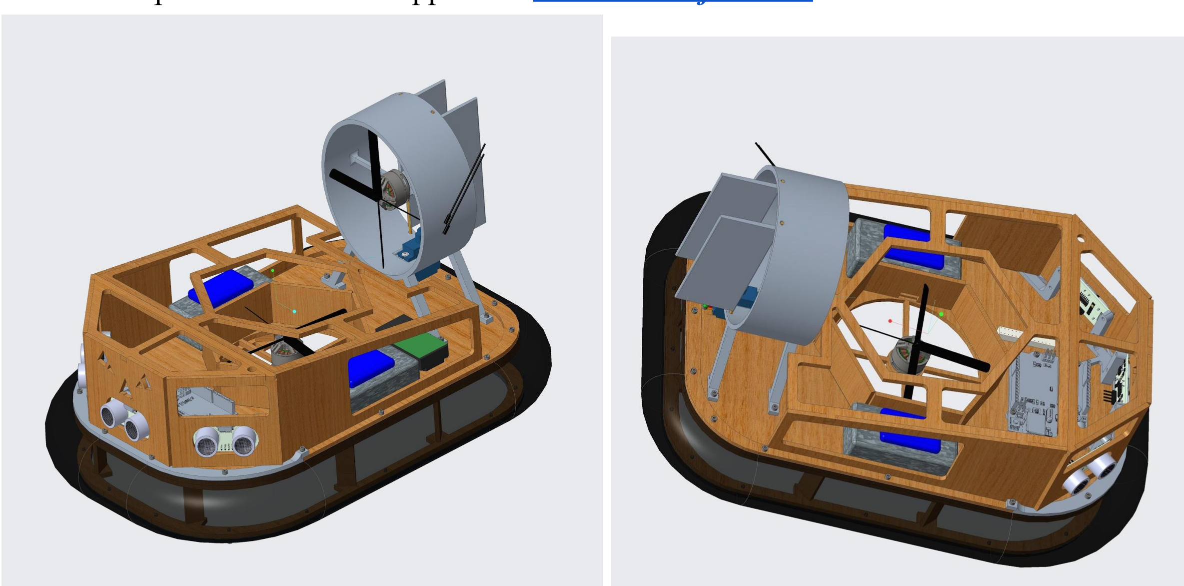


Figure 21: Circuit Diagram of Albert 2.0

Cost Analysis

Final Prototype Cost

The cost of all of the components for the final prototype is $338.45 however we estimate the total cost of the actual prototype to be around $279.13. The breakdown of the cost can be seen in the Appendix: ***Bill of Materials***. Referring back to Table 1, comparing the cost of *Albert 2.0* to existing miniature vehicles on the market, our hovercraft cost is competitive with quadrotors and RC cars while also including autonomous features. ALthough it is more expensive than the mini-hovercraft, our prototype provides a longer runtime, more durable design, as well as more control over the hovercraft's motion. Overall the cost of manufacturing a single prototype of *Albert 2.0* is more expensive than reproducing them in bulk. This is because the majority of our expensive components actually are sets of materials like nuts and bolts, screws, and balsa wood. Each of which can be bought in bulk for less. In addition, our most expensive components are the electronics, which if bought in units of 100 or 1,000 would bring down the overall cost per prototype.

Conclusion

We did it! Overall our team was able to deliver all of the client's design criteria while coming up with our own unique hovercraft design. *Albert 2.0* successfully integrates autonomous braking with the use of his ultrasonic sensor array, or his eyes. He is also capable of traveling over any non-porous 2D plane. The overall performance of our final design can be seen in Albert 2.0 final video.

https://drive.google.com/file/d/1rQbskZex6RX-WHIAst2tKotoIGgKGpuh/view?usp=sharing

Future Developments

For future developments around the hovercraft model, we looked into using carbon fiber as a base platform. It is stronger than balsa wood and has other material advantages such as the sleek look as well as environmental durability. The casing is also another area of development. As of now, the casing we have is not a marketable casing. With more time and modeling, a very sleek and well manufactured case that has balanced material properties with cost, can be developed. The casing would also need to be able to organize the electrical components within the hovercraft. The skirt installation is also an area of development. The replacement of the skirt can be a hassle since we are using screws and glue. Having some kind of frame that can be easily installed with the skirt would be a manufacturing advantage when marketing this product. The sensors are also an area for improvement. The ultrasonic sensor is a very efficient sensor for the task of sensing a nearing obstacle. However, there are more powerful sensors such as LiDar sensors and Infrared sensors. Use of new sensors and upgraded programming can lead to very advanced hovercraft technology. GPS is another development that can be added. Being able to locate where the hovercraft is as well as giving it coordinates to move to can be a huge development. This would lead to an additional development, which is automated control. Being able to enter in a destination and have the hovercraft autonomously locate to the specified coordinates is an advancement in the technology that we are presenting in the current model.

References

Image Citations:

[1] https://www.dji.com/mavic-air-2?site=brandsite&from=landing_page

[2]https://www.amazon.com/Control-SYMA-Hovercraft-Speedboat-Reminder/dp/B083J2CLHK/ref=sr_1_2?dchild=1&keywords=rc+hovercraft&qid=1619482757&sr=8-2

[3]https://laegendary.com/collections/weekend-deals/products/1-10-scale-remote-control-car-65km-h-brushless-blue-yellow

Brushless Motors

https://www.amazon.com/DYS-Brushless-Outrunner-Multirotor-Quadcopter/dp/B077HYQLMP/ref=sr_1_16?dchild=1&keywords=1400+kv+motor&qid=1607888876&s=toys-and-games&sr=1-16

https://www.amazon.com/gp/product/B06XBXRH6J/ref=ppx_yo_dt_b_asin_title_o02?ie=UTF8&psc=1

RC Controller and Receiver

https://www.amazon.com/gp/product/B0744DPPL8/ref=ppx_yo_dt_b_asin_title_o00_s00?ie=UTF8&psc=1

https://www.flysky-cn.com/fsi6x

Electronic Speed Controller

https://www.amazon.com/gp/product/B071GRSFBD/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1

Appendices

Bill of Materials

Item	Quantity	Amazon Link	Price/Unit [$]	Total Price [$]

24x12 balsa wood sheets	1 set, or 12 sheets	https://smile.amazon.com/dp/B07CHX1GTD/?coliid=I22AO7SUSGLP4E&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	19.45	19.45
M2 nut and bolt set	1 set	https://www.amazon.com/dp/B01N1WDUK0/?coliid=IEXGOAPXI1LCV&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	10.99	10.99
M1 nut and bolt set	1 set	https://www.amazon.com/dp/B07QB2LWN8?psc=1&ref=ppx_yo2_dt_b_product_details	13.99	13.99
Ripstop Nylon Sheeting	1 set	https://www.amazon.com/dp/B00ZR81X56/?coliid=I3TI7GRT6SCWD3&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	8.95	8.95
BYS 2300 KV brushless motor	2*	https://www.amazon.com/dp/B076H261PX/?coliid=I2CGFSZ37MC3C9&colid=24OCX7GALXU9S&psc=0&ref_=lv_ov_lig_dp_it	14.99	29.98
30A esc	2*	https://smile.amazon.com/gp/product/B071GRSFBD/ref=ppx_yo_dt_b_asin_title_o01_s00?ie=UTF8&psc=1	16.49	32.98
Tattu 1300 mAh LiPo battery	2*	https://smile.amazon.com/dp/B013I9SYC0/?coliid=I1QVS6PCQGE1K8&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	18.99	37.98
4 blade propellers	2*	https://smile.amazon.com/gp/product/B007AFYNZG/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&psc=1	7.79	15.58
Gorilla glue	1	https://www.amazon.com/dp/B082XGL21J/?coliid=I3TJF1PBHX79BW&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	7.99	-

Wood glue	1	https://www.amazon.com/dp/B07LGKHW5R/?coliid=I1SRQEQMKKXOUU&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	10.99	-
Jumper cable set	1 set	https://www.amazon.com/EDGELEC-Breadboard-Optional-Assorted-Multicolored/dp/B07GD2BWPY/ref=sr_1_3?dchild=1&keywords=wire+connectors+jumper+cables&qid=1620232987&sr=8-3	5.99	5.99
Arduino UNO	1	https://www.amazon.com/Arduino-A000066-ARDUINO-UNO-R3/dp/B008GRTSV6/ref=sr_1_3?dchild=1&keywords=arduino&qid=1620232916&sr=8-3	20.26	20.26
Ultrasonic sensor	3	https://www.amazon.com/dp/B01JG09DCK/?coliid=IPMXI52BKFNO1&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	9.99	29.97
Flysky FS-i6 controller and receiver	1	https://smile.amazon.com/dp/B0744DPPL8/?coliid=IWBNXLHRHATY0&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	55.99	55.99
100mm long 2mm diameter stainless steel axles	1	https://www.amazon.com/Yeeco-100Pcs-Stainless-100mmx2mm-Helicopter/dp/B07232VWLT/ref=sr_1_1?dchild=1&keywords=100mm+2mm+axle&qid=1620233018&sr=8-1	12.99	12.99
RGB LED light	1		1.98	1.98
Small zip ties	1 pack	https://www.amazon.com/dp/B01018DB2E/?coliid=I8ONHVAPNUL3P&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	4.99	4.99

Electrical Tape	1 roll	https://www.amazon.com/dp/B07ZWC2VLX/?coliid=I3HG3T4U7PLXZM&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	4.99	4.99
Double Sided Tape	1 roll	https://www.amazon.com/dp/B009NP1OBC/?coliid=I26LFOR3WLXO8S&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	9.88	9.88
Breadboard	1	https://www.amazon.com/dp/B07PCJP9DY/?coliid=I201DWWXDM6WE1&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	5.99	5.99
Front Ring	1		0.43	0.43
Rudder and Motor Mount	1		2.10	2.10
Plastic Sheeting	1	https://www.amazon.com/dp/B07MQTDF4R/?coliid=I3J2RH79OD0D19&colid=24OCX7GALXU9S&psc=1&ref_=lv_ov_lig_dp_it	9.45	9.45
Total	-	-	-	**334.91**

** We recommend purchasing one additional unit of these materials, as they can be damaged or broken easily.*

Part Specs and Sheets

	ALL ITEMS	
esc	blue esc	40
	yellow esc	28
servos	blue servo	9
	black servo	9
batteries	tattu 1550 mAH	135
	POVWAY 2200 mAh	189
	9v duracell w/ adapter	48
motors	BYS 2300 kV brushless	24
	generic 1400 kV brushless	53
	centrifugal blower fan	218
Arduino	withouout motor shield	27
	with motor shield	64
	total	302

Albert 1.0		
	Item	**weight (grams)**
esc	blue esc	40
	blue esc	40
servos	blue servo	9
batteries	tattu 1550 mAH	135
bullet cable splitter		
reciever		
motors	BYS 2300 kV brushles	24
	BYS 2300 kV brushles	24
craft body		
props		
TOTAL		272

Albert 2.0		
	Item	**weight (grams)**
esc	blue esc	40
	blue esc	40
servos	blue servo	9
batteries	tattu 1300 mAH	122
	tattu 1300 mAH	122
cabling		
motors	BYS 2300 kV brushless	24
	BYS 2300 kV brushless	24
Craft Body	wooden components	
	Prop Motor Mount	
	Sensor Mount	
	External housing	
Circuit	Arduino	27
	Ultrasonic range finder	
Total		408

Circuit Diagram

Figure 22 shows the layout of our circuit among all the hardware components on Albert 2.0. An Arduino UNO is pl
aced as the brain of Albert 2.0. It processes our software program and outputs the necessary signals to all the other components (ultrasonic sensor array, ESCs, and RGB LED).

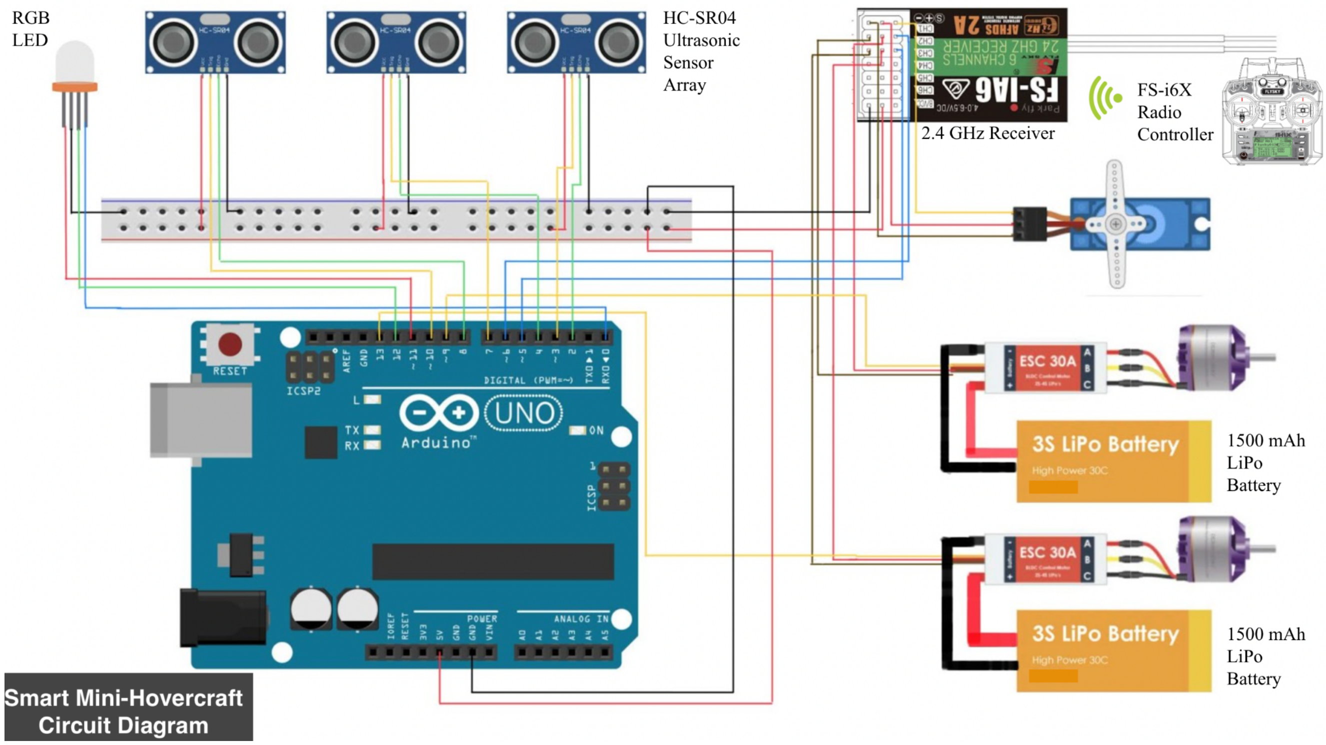
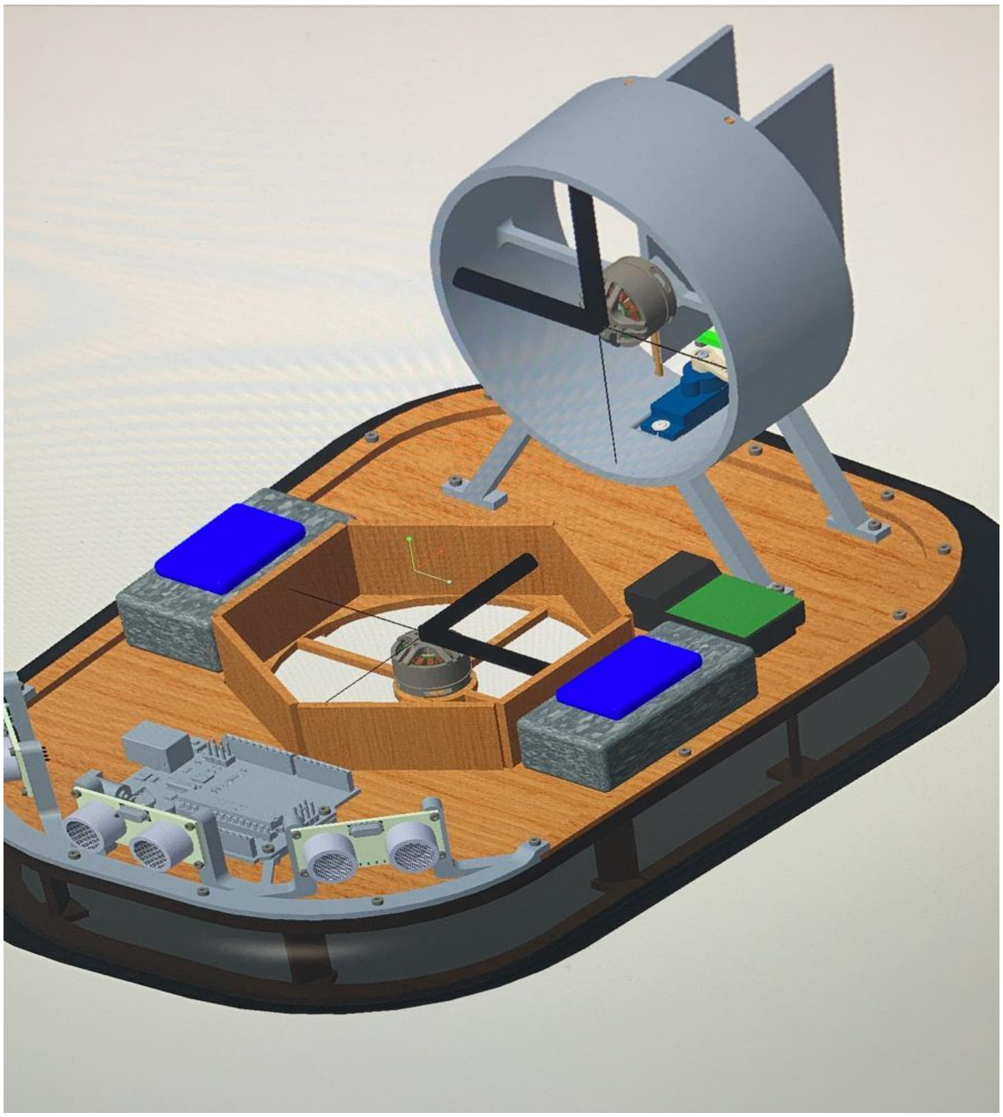


Figure 22: Circuit Diagram of Albert 2.0

CAD Depository

https://drive.google.com/drive/folders/1E_WJI6xzSDaQElmEaknlR4xV8dqWvqWv?usp=sharing



Code Depository (Arduino IDE)

/* This code serves for the BU ME461 Team 11's Smart Mini-Hovercraft senior design project.
It functions to remote control the hovercraft with FS-i6X and remote controller and FS-iA6B channel receiver.
It also let the hovercraft be able to use the ultrasonic sensor array to detect obstacles
and conduct certain actions when it detects obstacles. It also includes a RGB light to indicate the safety level of the current position. Written by Chuwei Chen | 2021 | chenchuw@bu.edu

```
Reference:
https://medium.com/@werneckpaiva/how-to-read-rc-receiver-signal-with-arduino-54e0447f6c3f
https://create.arduino.cc/projecthub/muhammad-aqib/arduino-rgb-led-tutorial-fc003e
*/

#include <Servo.h>

// Channel 1: Servo (Not implemented here), Channel 2: Propeller, Channel 3: Lifter
#define CH2 5 // Propeller
#define CH3 6 // Lifter

const int Trigger_Front = 11; // Trigger Pin of Ultrasonic Sensor
const int Echo_Front = 8; // Echo Pin of Ultrasonic Sensor
const int Trigger_Left =7;
const int Echo_Left = 4;
const int Trigger_Right = 3;
const int Echo_Right = 2;

int red_light_pin= 10;
int green_light_pin = 12;
int blue_light_pin = 0;

Servo ESC_propeller;
Servo ESC_lifter; // Under construction!

// Read the number of a given channel and convert to the range provided.
// If the channel is off, return the default value
int readChannel(int channelInput, int minLimit, int maxLimit, int defaultValue){
  int ch = pulseIn(channelInput, HIGH, 30000);
  if (ch < 100) return defaultValue;
  return map(ch, 1000, 2000, minLimit, maxLimit);
}

void setup(){
  Serial.begin(115200);
  ESC_propeller.attach(9,1000,2000);
  ESC_lifter.attach(13,1000,2000);
  pinMode(CH2, INPUT);
  pinMode(CH3, INPUT);
}

int ch2Value, ch3Value, ch2speed, ch3speed;

void loop() {
```

```
// Sensors
long duration_front, cm_front, duration_left, cm_left, duration_right, cm_right;
 // Front sensor
 pinMode(Trigger_Front, OUTPUT);
 digitalWrite(Trigger_Front, LOW);
 delayMicroseconds(2);
 digitalWrite(Trigger_Front, HIGH);
 delayMicroseconds(10);
 digitalWrite(Trigger_Front, LOW);
 pinMode(Echo_Front, INPUT);
 duration_front = pulseIn(Echo_Front, HIGH);
 cm_front = ms_to_cm(duration_front);

 // Left sensor
 pinMode(Trigger_Left, OUTPUT);
 digitalWrite(Trigger_Left, LOW);
 delayMicroseconds(2);
 digitalWrite(Trigger_Left, HIGH);
 delayMicroseconds(10);
 digitalWrite(Trigger_Left, LOW);
 pinMode(Echo_Left, INPUT);
 duration_left = pulseIn(Echo_Left, HIGH);
 cm_left = ms_to_cm(duration_left);

 // Right sensor
 pinMode(Trigger_Right, OUTPUT);
 digitalWrite(Trigger_Right, LOW);
 delayMicroseconds(2);
 digitalWrite(Trigger_Right, HIGH);
 delayMicroseconds(10);
 digitalWrite(Trigger_Right, LOW);
 pinMode(Echo_Right, INPUT);
 duration_right = pulseIn(Echo_Right, HIGH);
 cm_right = ms_to_cm(duration_right);

 Serial.print("Front sensor: ");
 Serial.print(cm_front);
 Serial.print("cm     ");
 Serial.print("Left sensor: ");
 Serial.print(cm_left);
 Serial.print("cm     ");
 Serial.print("Right sensor: ");
 Serial.print(cm_right);
 Serial.print("cm     ");
```

```
  // ESCs
  ch2Value = readChannel(CH2, 0, 100, 0);
  ch3Value = readChannel(CH3, 0, 100, 0);
//  if (ch2Value < 50)
//    ch2Value = 50;
  ch2speed = map(ch2Value, 50, 100, 1000, 2000); // 50(middle joystick), 100 (top joystick),
1000 (0 speed), 2000 (max speed)
  ch3speed = map(ch3Value, 0, 100, 1000, 2000); // 0(bottom joystick), 100(top joystick).

  // Important variables here: cm_front,cm_left,cm_right, ESC_lifter, ESC_propeller

  // Determine current situation: var=1 all green, var=2 one or more blue, var=3 one or more red.
  // Green(safe): nothing ahead, Blue(careful): something in between 20-30cm, Red(warning):
something in 20cm.
  int varr = 0;
  // Nothing around:
  if (cm_front >= 30 and cm_left >= 30 and cm_right >= 30) varr = 1;
  // Be careful:
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_front < 30) varr = 2;
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_left < 30) varr = 2;
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_right < 30) varr = 2;
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_front < 30 && cm_left <
30) varr = 2;
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_front < 30 && cm_right <
30) varr = 2;
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_right < 30 && cm_left <
30) varr = 2;
  else if (cm_front >= 20 && cm_left >= 20 && cm_right >= 20 && cm_right < 30 && cm_left < 30
&& cm_front < 30) varr = 2;
  // Too close:
  else varr = 3;


  // Obstacle-detected Decision Making && Remote Control
  // Green: do nothing, Blue: do nothing, Red: brake and delay 1s for user lowering speed.
  switch (varr) {
  case 1:
    RGB_color(0,255,0);
    ESC_lifter.write(ch3speed);
    if(ch2speed > 990)
      ESC_propeller.write(ch2speed);
    break;
```

```
 case 2:
   RGB_color(0,0,255);
   ESC_lifter.write(ch3speed);
   if(ch2speed > 990)
     ESC_propeller.write(ch2speed);
   break;

  case 3:
   RGB_color(255,0,0);
   ESC_lifter.write(1000);
   if(ch2speed > 990)
     ESC_propeller.write(1000);
   delay(1000); // Delay 1second for user to lower the speed
   break;

   default:
   ESC_lifter.write(ch3speed);
   if(ch2speed > 990)
     ESC_propeller.write(ch2speed);
   break;
 }

 Serial.print((int)varr);
 Serial.print(" Ch2: ");
 Serial.print(ch2Value);
 Serial.print(" Propeller Speed: ");
 Serial.print(ch2speed);
 Serial.print(" Ch3: ");
 Serial.print(ch3Value);
 Serial.print(" Lifter Speed: ");
 Serial.print(ch3speed);
 Serial.print('\n');
 delay(100);
}

long ms_to_cm(long microseconds) {
  return microseconds / 29 / 2;
}

void RGB_color(int red, int green, int blue)
 {
 analogWrite(red_light_pin, red);
 analogWrite(green_light_pin, green);
 analogWrite(blue_light_pin, blue);
```

}

Instruction Tron

https://docs.google.com/document/d/1HY5UlZwj350wma9EAkZJSSm2BFaVOTxRsESOI8X2-Ck/edit?usp=sharing