

UNDERGRADUATE REPORT

Construction of a Hovercraft Model and Control of its Motion

by Jeffrey Schleigh

Advisor:

UG 2006-5



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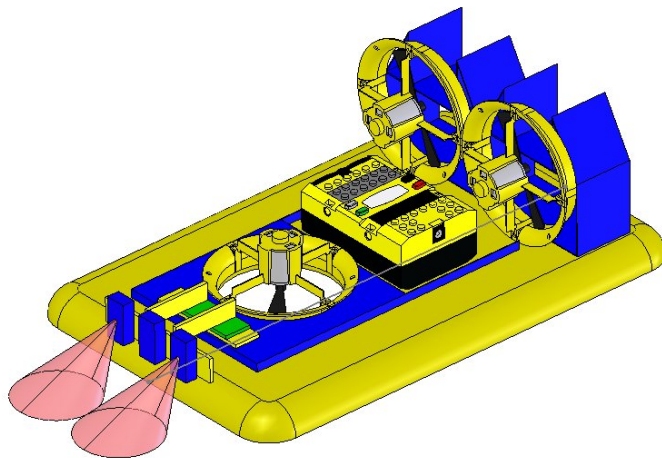
Research Experience for Undergraduates

Institute for Systems Research

Construction of a Hovercraft Model and Control of its Motion

Jeffrey Schleigh

Advisor: Dr. Guangming Zhang

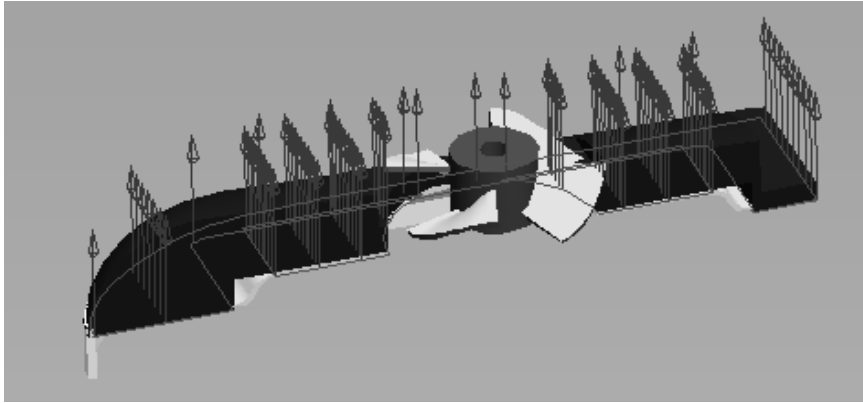


Abstract

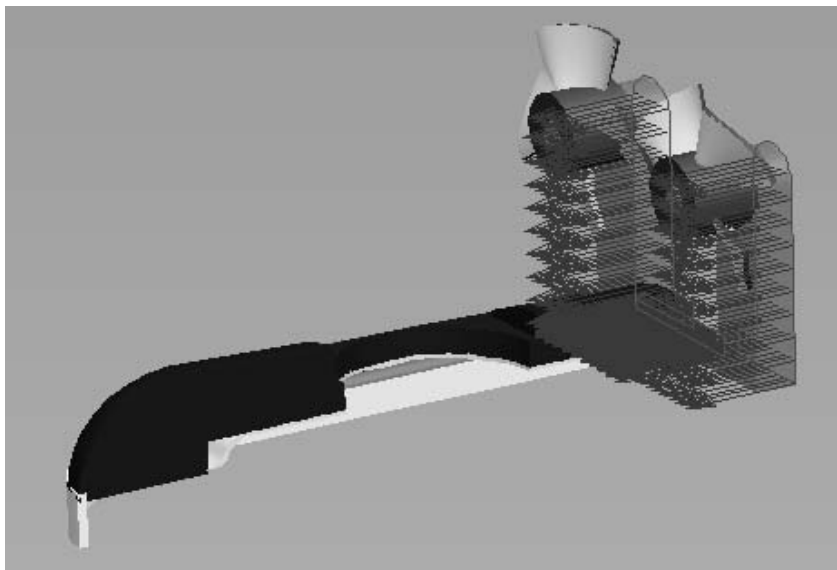
For this research project, there are two basic requirements. The first requirement is to design and construct a physical model of a hovercraft prototype. The second requirement is to control the motion of the constructed hovercraft prototype, such as following a track, which consists of straight lines and curves. There are three software systems available in the completion of this research project. These systems are Pro/ENGINEER, SolidWorks and Robotics Invention System.

Introduction

A hovercraft is a special type of vehicle that moves on a cushion of air. The lifting motion is controlled by a fan or fans so that an air gap can be formed. Such separation between the bottom of the hovercraft and the ground provides a motion platform, on which the friction force between the hovercraft and the ground reduces to a very small amount.



Since a hovercraft does not have wheels, the forward motion is created through the propelling action, which is generated by the use of a propulsion fan and/or a set of fans. These propelling fans send air out of the back of the hovercraft to produce a thrust force, which moves the hovercraft forward.



The following two pictures are from a website illustrating the use of hovercraft as a vehicle to accomplish a mission of transferring military vehicles over the water to a desert area.



There are four parts in this final report:

1. Design of a hovercraft model using Pro/ENGINEER and SolidWorks.
2. Calculation of the Lifting Pressure
3. Construction of a hovercraft model.
4. Control of the motion of the constructed hovercraft model.

Design of a Hovercraft Model

During the first two weeks, a literature survey on the subject of hovercrafts was conducted. For example, the website www.airfloat.com illustrates how an airflow bearing works. By utilizing the high air pressure to lift the cargo, the presence of an air gap enables it to move the heavy cargo with much less force.



One website that provides a great amount of information on the subject of hovercraft products commercially available for customers to purchase is www.hovercraft.com. Specifications of a product are detailed in terms of the product size, speed range, weight and power consumption. The following information is obtained from a screen capture of UH-15TA model.

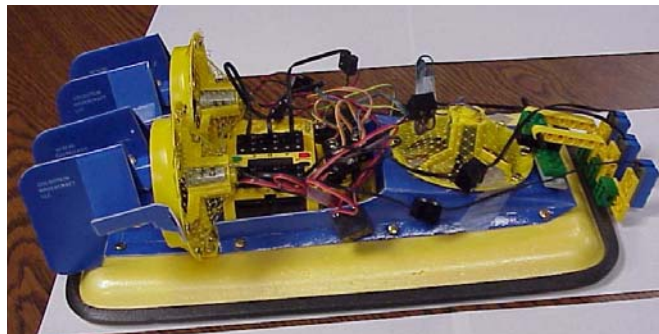
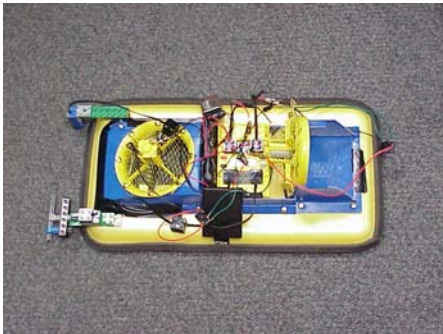
UH-15TA

The UH-15TA features a polystyrene foam core with aluminum skin. The thick foam core hull provides fail-safe positive flotation and improved rough water handling.



Capacity	4 Persons
Payload	700 to 1000 Lbs
Speed	50 to 60 mph
Hover Height	11 inches
Length	15 ft 7 in
Width	7 ft 6 in
Empty Weight	500 to 600 Lbs
Flotation	3000 Lbs
Climb Gradient	25 to 30%
Engines	10 to 15 hp lift (under 80 lbs), 40 to 90 hp 440cc or larger 2-cycle thrust
Construction Method	Foam Core with Aluminum Skin
Construction Time	250 to 400 hours

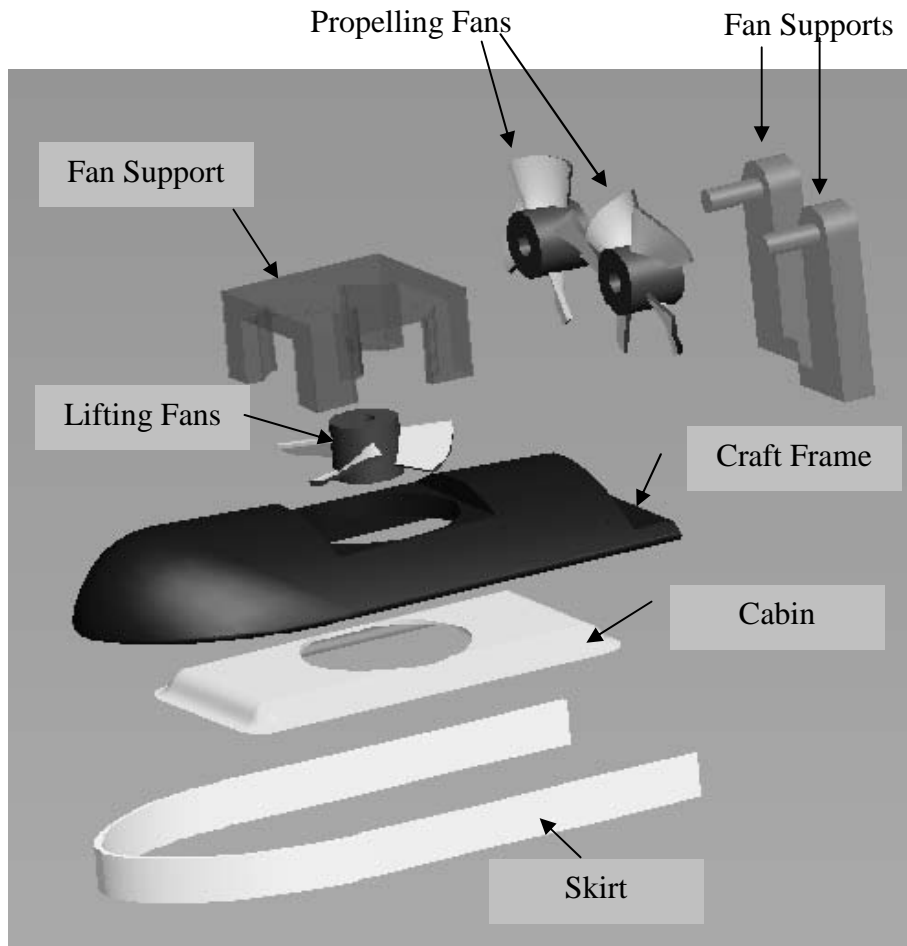
One company that offers inexpensive kits and other instructional tools is Goldstein Hovercraft, LLC, which can be found at www.gohover.com, owned by Mr. Eric Goldstein. The company supplies a construction kit with detailed information through the provided construction menu. All kits have a design-it-yourself feature which allows kids to express both engineering and artistic creativity. We contacted Mr. Goldstein in June and he was very generous to provide us with two construction kits. The first construction kit was for a hovercraft model with one lifting fan and one propelling fan. The second construction kit was for a hovercraft model with one lifting fan and two propelling fans. We constructed these two hovercraft models, as shown below.



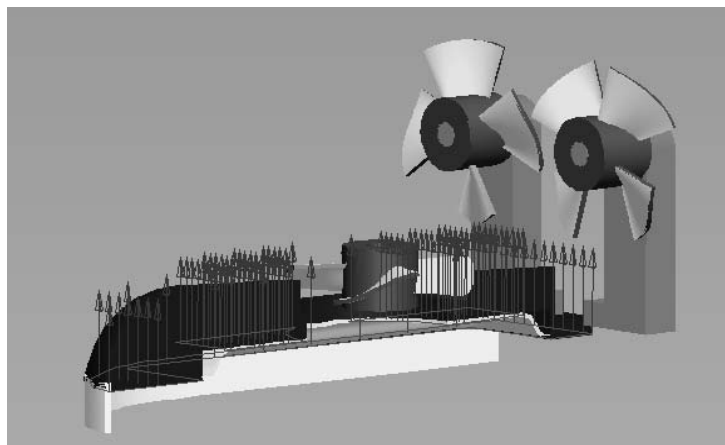
With reference to the two constructed hovercraft models, a computer simulation model of a hovercraft to be used by ENES100 students was created. This was done because Dr. Zhang has been assigned to teach ENES100 in the fall semester of 2006. Under the guidance of Dr. Zhang, the 3D solid model mainly consisted of the following components:

1. A central lifting fan
2. Support for the lifting fan
3. Two (2) propelling fans
4. Support for the 2 propelling fans

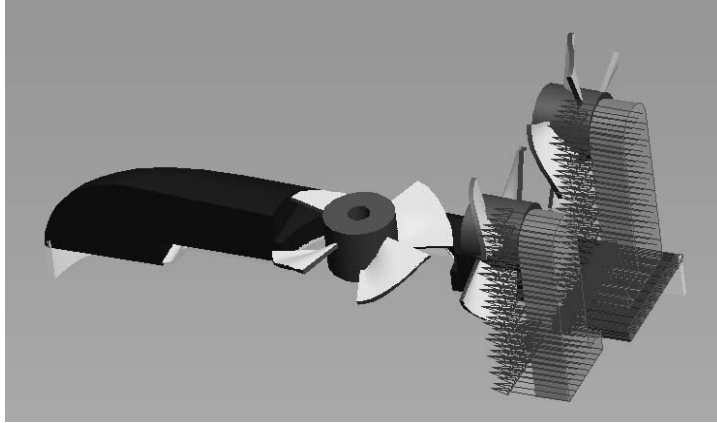
5. Frame of the hovercraft
6. Air cabin
7. Skirt



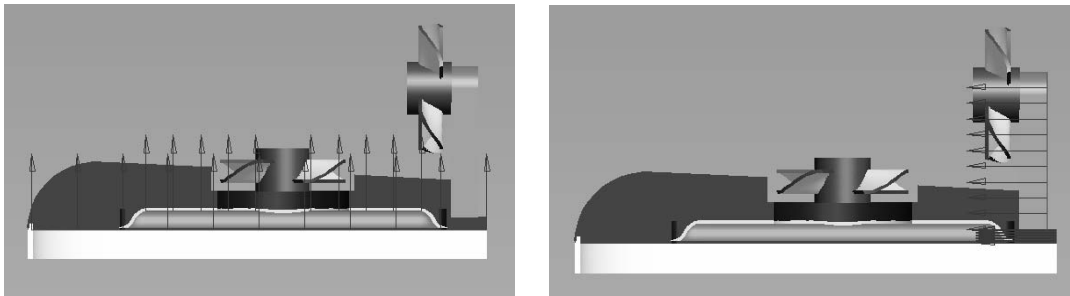
The lifting fan is placed in the central location of the hovercraft to provide the force required to lift the hovercraft and form an air gap between the hovercraft and the ground.



The two propelling fans are located at the rear part of the hovercraft to generate the thrust action, which pushes the hovercraft forward.



The following two pictures illustrate how this designed hovercraft to work when the three fans are set to operation.



Calculation of the Lifting Distance

The equivalent mass density of the craft frame is assumed as 2.5 gram/cm^3 . The total volume of the craft frame is 3.92 mm^3 . As a result, the total mass of the craft frame is given by

$$total_mass = (volume)(density) = (3.92 \times 10^3)(2.5) = 981(\text{grams})$$

$$total_weight = (mass)(gravity_const) = (0.981)(9.81) = 9.62(\text{Newtons})$$

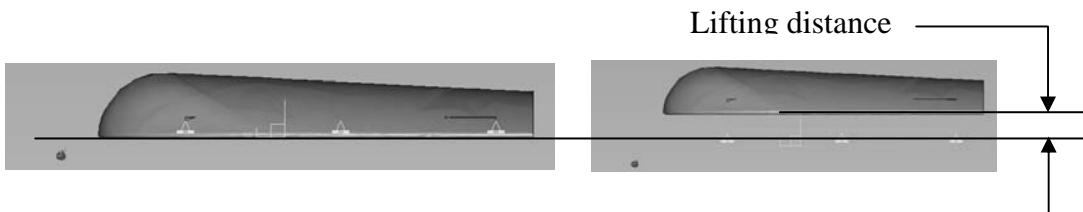
At a dynamic equilibrium condition, the lifting force is equal to the total weight of the hovercraft model in magnitude, but in an opposite direction. As a result, we are able to predict the pressure generated by the lifting fan, assuming the lifting area is equal to 0.075 m^2 .

$$total_weight = (lifting_pressure)(acting_area)$$

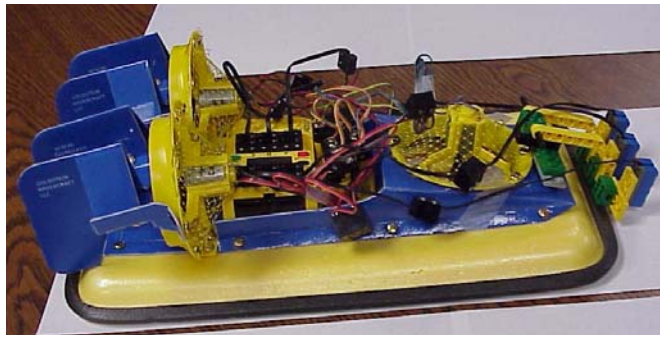
$$9.62 = (lifting_pressure)(0.075)$$

$$lifting_pressure = \frac{9.62}{0.075} = 128(\text{N} / \text{m}^2) = 0.019(\text{psi})$$

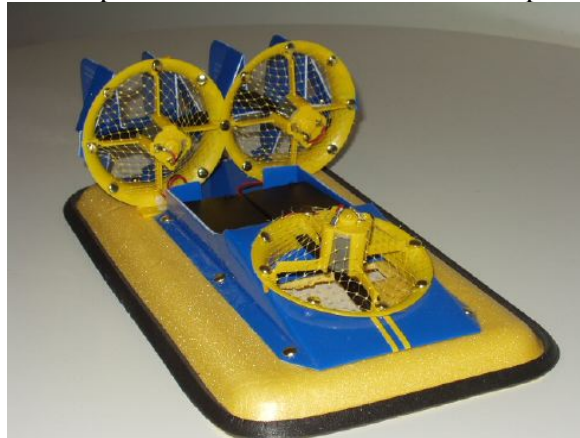
From the calculated lifting pressure, we will be able to calculate the lifting distance although such calculation needs several more assumptions, such as the volume of the air flow with its rate, no tilt of the hovercraft frame, etc. The following picture is screen capture of the computer simulation obtained when Pro/Mechanica was used.



Control of the Motion of the Constructed Hovercraft



As illustrated, the hovercraft model kit came with all the appropriate parts to construct it. The parts included: foam trays, for the base of the hovercraft; foam tape, to protect the base; flat, blue foam that was used as the body; motors and propellers, to make the fans; motor covers; battery holders; brass fasteners, to connect everything; Velcro dots, to attach the battery holders to the base; netting, to cover fans for protection. Once the model was constructed, it looked similar to the one pictured below, with the only difference being the additional parts that were added to increase its performance level.

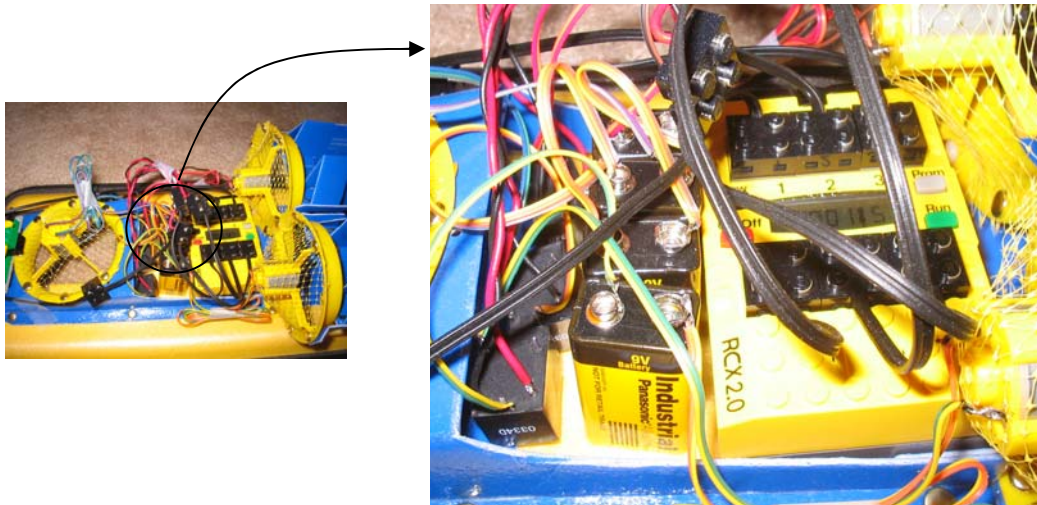


The additional parts added to the hovercraft for better performance were parts from the Robotics Invention System Kit, electronic power switches, and stronger batteries. The Robotics Invention System Kit is used to build various robots from LEGO pieces that are controlled using a built in controller. From the Robotics Kit, the parts added to the hovercraft were three light sensors as shown below:

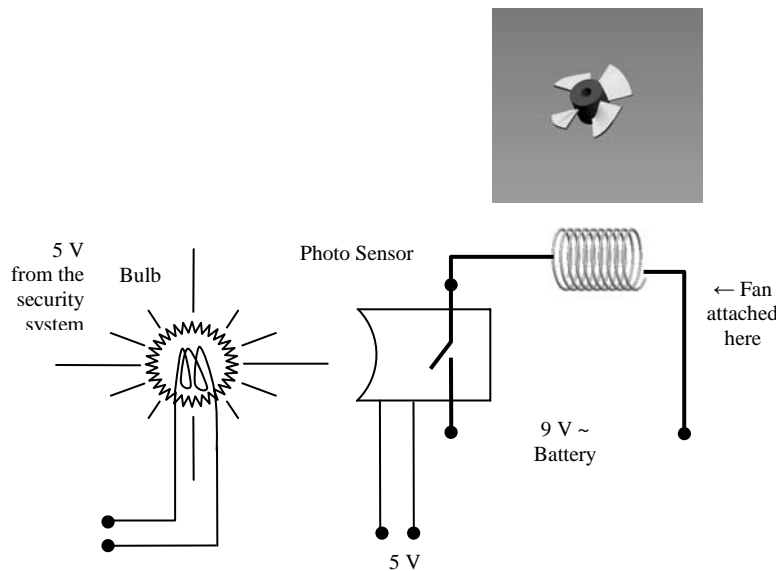


The light sensor on the left side is used to monitor the occurrence of deviations towards the left side during the motion. The light sensor on the right side is used to monitor the occurrence of deviations towards the right side during the motion. The light sensor located in the middle is used to monitor the deviation to either side.

The LEGO system has a controller, called an RCX. When a light sensor detects a deviation, it will send a TTL signal to the RCX. Through a user's program, a correction signal can be generated to turn off a corresponding propelling fan so that a path correction can be made to bring the hovercraft back to the track during motion. The RCX box is shown below.

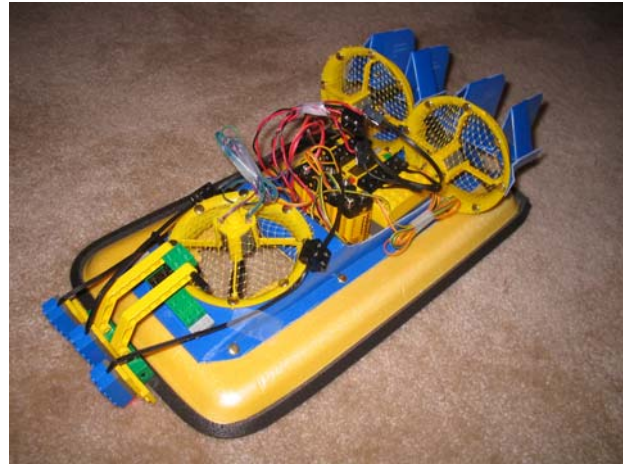


However, the power available to supply the driving motion is sufficient for the LEGO used motors, but is far less sufficient to drive either the lifting fan or the two propelling fans. In order to resolve this difficulty, a relay device was used. The RCX controls the on/off switch of a relay. The on/off switch of the relay controls the on/off of switch the lifting fan or a propelling fan.



After performing several tests on the power of the fans, a conclusion was made that the controller was not strong enough to run the fans at an appropriate speed to allow the hovercraft to move in the

upward direction. The current coming from controller was not enough to run the fans at full speed, so an electronic switch was added. One switch was wired to each fan. The figure above shows the operation of the switch. A small current is applied from the RCX controller, which switches on a light that causes the loop to close and a large current is applied to the fan. The switches can be seen below (left). In addition to adding a switch, a 9V battery for each propulsion fan and two 9V batteries for the lift fan were added to get more power, instead of 4-AAA batteries. The finished hovercraft, after the addition, performance enhancing parts were added on, is pictured below (right).

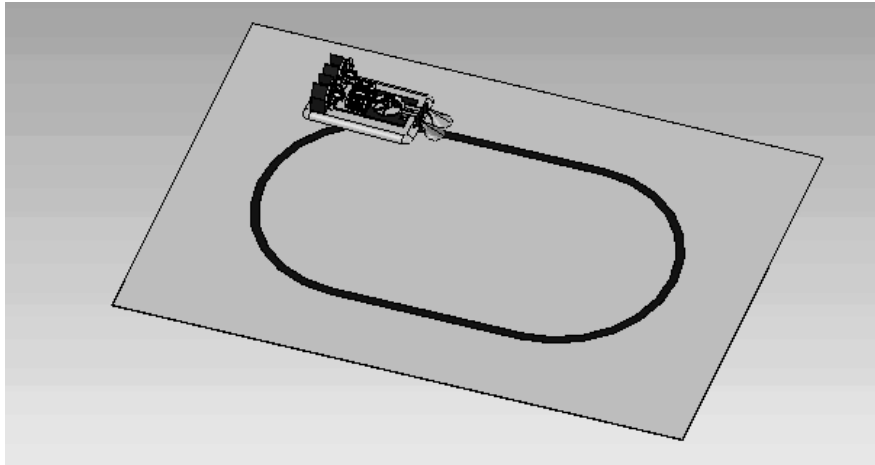


Programs to Control the Motion of the Constructed Hovercrafts

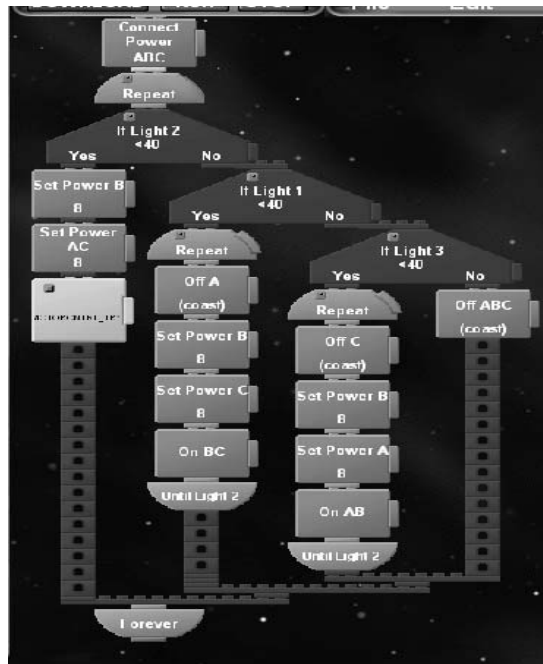
The program, used to operate the fans and light sensors on the hovercraft, was written with Robotics Invention System. The RCX controller, wired to the hovercraft, receives a signal from the computer using a USB tower. The tower is what transfers the program to the controller to operate the hovercraft. The main purpose of the program was to turn the fans on and off, and to have the light sensors recognize specific colors so the hovercraft can move about. There were two different programs written for the hovercraft. The first program was written to have the sensors follow a single black strip of tape that would guide the hovercraft along its path. For the second program, the sensors followed a white path that was bordered in by two black strips on either side, which also guided it.

The hovercraft prototype that was selected for testing has three different fans, one lift fan and two propulsion fans. To make the hovercraft move forward all three fans must run simultaneously. When the hovercraft makes a turn the opposing fan to the direction of the turn will turn off for the amount of time needed to complete the turn. For example, if the program detects that the hovercraft must turn to the right, the left thrust fan will turn off until the hovercraft is back on track. The hovercraft stops when all three fans are turned off. The fans are turned on and off depending on the path the hovercraft needs to follow.

The sensors, used to keep the hovercraft on the path of black tape, are spread across the front of the hovercraft. The main light sensor, placed directly center, is the one that the hovercraft follows. The other two light sensors are placed just off to each side of the main sensor. Those light sensors are used to identify when the hovercraft has gone off path. When one of the two side light sensors pick of the black tape, the fan on that side turns off to make a turn in that direction until the main (center) light sensor picks the color of the black tape. Once the main light picks of up the black tape, all three fans will again run simultaneously, and the hovercraft will move forward. The cycle continuously repeats as the hovercraft moves along the path of black tape, as shown below.



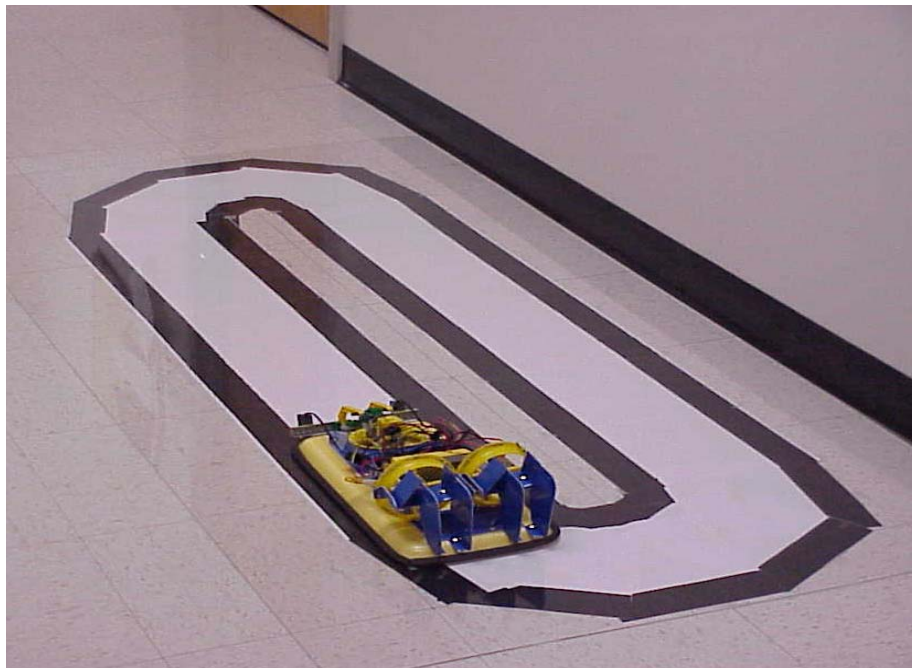
The different operations stated in the previous paragraphs are all written into the program. The flow chart of the program is pictured below. In the chart below, the letters A, B, and C are the variables for the fans, and Lights 1, 2, and 3 are for each one of the light sensors. The light sensor reads a value for the colors that it picks up. The black tape reads a specific numerical value (less than 40), so any reading coming up less than that value is what makes the light sensors react. The hovercraft is only moving when one of the three sensors is reading less than the value it reads when it sees the black strip.



The second program was written for the hovercraft to follow a different path. The path is white and has black strips acting as borders for it to follow. In order to appropriately follow this path, the two light sensors were moved to the outside corners on the front of the hovercraft, as shown below. Note that the center one was removed.



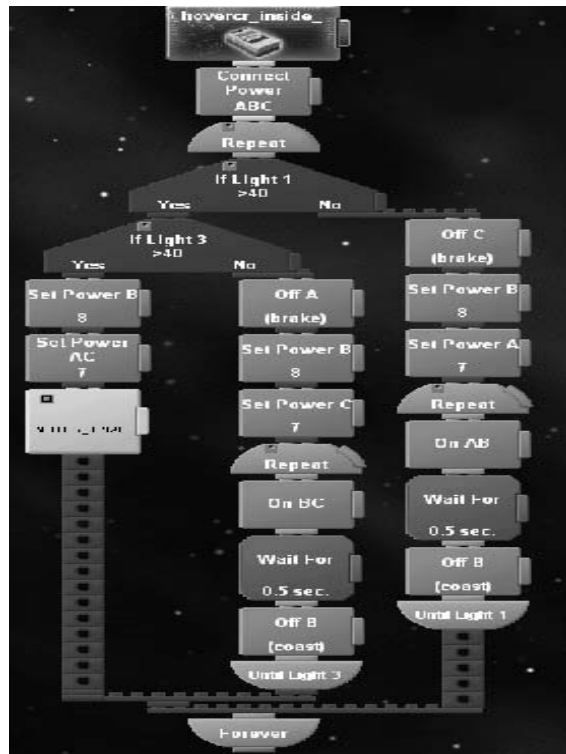
The two light sensors, now moved to the outside of the hovercraft, are set to pick up the black strip the same way it did in the first program. When both light sensors are reading the value for the white path, then all fans run simultaneously for the hovercraft to move forward. If the hovercraft goes off course one of the light sensors will pick up the value of the black strip and will react. The reaction depends on which light sensor is reading the value of the black strip.



Similar to the first program, the light sensors catch the hovercraft when it goes off track. Once one of light sensors pick up the black tape, the fan on the opposite side will cut off and make the hovercraft turn in the opposite direction it started to turn. When both lights read the value of the white path, all fans begin to run again, and the hovercraft proceeds to move forward. The black strips act as borders for the white path, and as the light sensors cross the border, the fans react to get it moving back on track. The figure above shows a picture of the hovercraft on the track.

The program, pictured below, shows the flow chart that continuously runs to operate the hovercraft. The program checks both light sensors, and as long as they are reading a value greater than 40

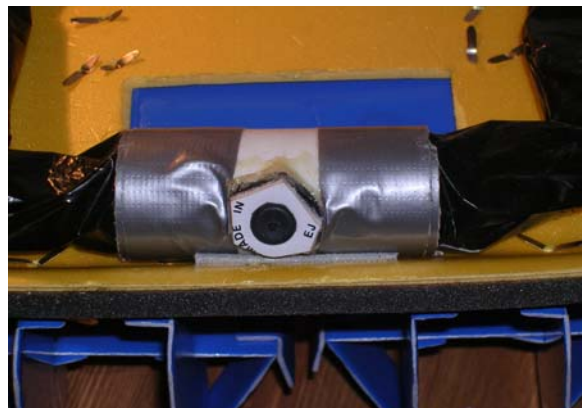
(black strips read less than 40), the hovercraft moves forward. If the light sensors do not read greater than 40, then they react by switching the fans on and off.



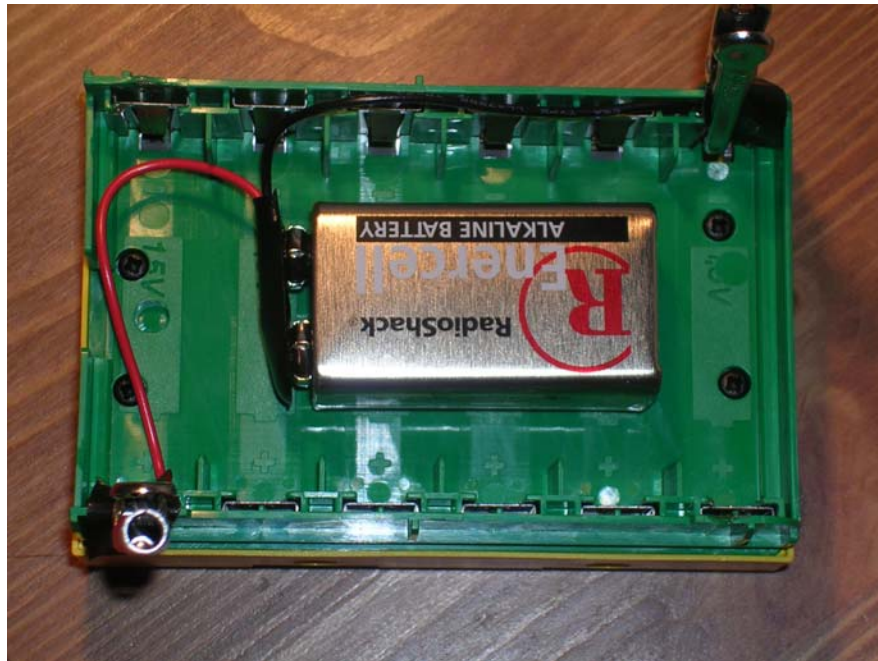
Analysis of Testing

Even though the program worked well, there were some errors that were identified after testing. One problem was that the additional components that were added for the program were too heavy for the lift fan. Two solutions were generated, resulting in increased performance.

The first solution was to add a skirt to the hovercraft to give some cushioning for the extra weight of the RCX. To construct this skirt, an air stopper from an ordinary playground ball was fitted to a 3" PVC pipe, which is shown below. The plastic bag tube was then attached to the PVC pipe and sealed in order to ensure that no air could escape from the skirt. The skirt was inflated using an air pump and secured to the bottom of the hovercraft. After this modification, the hovercraft could support more weight.



In addition to the skirt, we determined that 9 volts were needed to run the RCX controller, but the RCX is configured to run on 6 AA batteries, totaling 9 volts. So to reduce the weight of the batteries, a 9V battery was wired to the RCX, thus eliminating the weight of several batteries. After this alteration was completed, the hovercraft lifted higher off the ground than it had previously. Additionally, the hovercraft is more cost effective based on the lower number of batteries required. This configuration is shown below.



Conclusion

The robotics invention hovercraft was very successful. After running several tests to get the best program to operate it, the hovercraft was able to travel at least half way around each course. The challenge was getting the hovercraft to react at a pace fast enough to keep it moving around the track, but not so fast for that it would be out of control. Doing so took a lot of adjusting with the weight of the hovercraft, the speed of the fans, and the reaction time. The only recurring problem that was encountered was the batteries losing power quickly. The batteries would only allow the hovercraft to run a few times. To fix that problem the batteries were replaced with new rechargeable ones as they started to lose power.

Reference Websites:

<http://www.gohover.com/> ,Goldstein Hovercraft, LLC's website

<http://www.airflow.com/>

<http://www.hovercraft.com/>

Acknowledgements

Dr. Guangming Zhang provided assistance on many topics regarding the hovercraft as an advisor on this research project. Mr. Kevin Lister of the Department of Mechanical Engineering provided a great help in the process of designing several components in Pro Engineer. Mr. Scott Posey, a design engineer at the Phoenix International at Baltimore, has provided the graphical pictures created under SolidWorks. Ms. Whitney Ademiluyi provided some assistance with RCX programming. Mr. Z. Wu at the Department of Mechanical Engineering also assisted in the process of constructing the relay circuits.