CSCE 439/839: Robotics
Lab 1: Hovercraft Construction and ROS

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Started: Tues, September 10, 2013
Lab 1 Checkpoint: Tues, September 17, 2013
Lab 1 Due Date: Thurs, September 26, 2013

1 Overview

In this lab you will design, construct, and perform experiments with the physical hovercraft. In addition, you will learn to use ROS (`www.ros.org`). This lab has a checkpoint. In lab on the date of the checkpoint you will be responsible for showing the instructor your progress. You are expected to complete up to and including Section 5.5 for the checkpoint; however, I would encourage you to have completed more than this by the time of the checkpoint.

Before starting you should read through the whole lab. Some parts can be done in parallel, while some sections rely on the completion of previous sections. You should discuss your plan of attack for the lab in your group and decide how you will work together and divide the work. Everyone, however, is responsible for knowing about all sections of the lab. In addition to completing the lab report, on the due date, you will demonstrate what you accomplished for the instructor.

2 Materials

The main materials you will use in this part of the lab to construct the hovercraft are:

- Sheet of 1.5 inch think rigid foam insulation
- 5mil plastic sheet
- Five Brushed GW/EDF40 Ducted Fans (thrusters)
- One Brushless GW/EDF40 Ducted Fan
- Wire, tape, brackets, screws, etc.

You will also use a various hand tools including knives, soldering irons, power supplies, etc.

3 Safety

In this lab you will be using a number of tools and devices that can be dangerous if mishandled. You should always follow instructions, think twice, and ask for help if you are unsure what you are doing or are unsure about safety. Please report any accidents to the course staff and seek medical attention immediately if needed. Reasonable precautions will prevent most accidents. Do not work in the lab alone or when you are tired.

Throughout this course you will be using ducted fans for propulsion of the hovercraft. These are relatively safe, but you should never put your fingers or anything else inside of them. Along these lines, if you have long hair, you should make sure to tie it back or cover it while in the lab.

We will also be using power supplies and batteries in this course. Make sure to follow instructions when using these devices as they can be dangerous if misused. You should always be careful not to short wires on batteries or power supplies and follow appropriate methods for charging batteries.

In this lab you will also be using sharp knives and soldering irons. These can cut or burn you or your classmates. Always be aware of your surroundings when using these devices and never cut towards yourself or anyone else.

We will be using high-power, two cell Lithium-Polymer (LiPo) batteries to power the hoverboard. Please be extremely careful with these batteries and recall the safety information we discussed in lab. In particular, only use the designated chargers in the lab to charge the batteries. The hoverboards will not turn on if the voltage on the battery is too low, however, you should also be aware of the use of your battery and never leave it connected to the hoverboard when not in use (as this could dangerously discharge the battery). A fully charged battery will have a voltage of 8.4V. A battery that is about half charged will have a voltage of approximately 7.4V, and a nearly discharged battery will have a voltage of around 7.0V. A voltage below 6.0V can be dangerous, especially if you try to recharge it. If this happens, please let the instructor know immediately. With care, it is possible to revive an over discharged battery if it is done quickly (but putting it on the charger is not the way to do it and it is dangerous).

Unlike most programming, it is possible that a bug in your code could physically damage your hovercraft or injure your classmates. Take care when running testing your hovercraft to make sure that everyone around you is aware of what is going on and that you are able to quickly stop your hovercraft when it goes out of your control.

4 Hovercraft Design and Construction (25pts)

In this section you will design and construct your hovercraft. The exact configuration will be left up to you. The only constraint is that the hovercraft must be omni-directional (able to translate in any direction) and it must have rotational control (ideally equal control clockwise and counterclockwise).

One of your goals in designing and constructing your hovercraft is to make it look nicer than mine. This shouldn't be too hard :)

4.1 Base

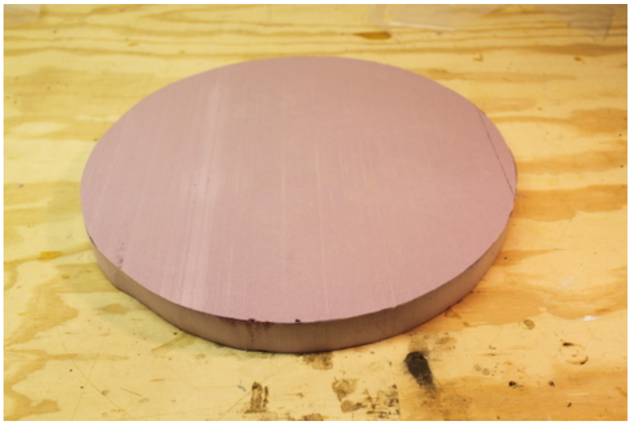

Figure 1: A foam circle cut out of the sheet of rigid foam.

For the base we will be using 1.5 inch rigid foam insulation. This is a lightweight material that is easy to work with and relatively inexpensive. There are a variety of circle templates that you can use ranging from about 12 inches to 17 inches in diameter. You are free to make your hovercraft whatever diameter you choose. The only constraints are that it should be larger than 10 inches in diameter and no more than 20 inches. You can also create other shapes, although I suggest you cut a circle as it makes creating a good skirt significantly easier.

To cut the foam, first lay your template circle on top of the foam. Select a portion of the foam that will result in as little wasted foam as possible. Trace a circle on the foam with a pen or marker. Remove the template and then carefully cut the foam out using provided knife. When using the knife extend the blade to a length slightly longer than the width of the foam and then use the locking nut to lock the blade in place. Make sure to keep the blade perpendicular the surface to ensure a clean cut. Small sawing motions may be helpful. Note, **you should cut the foam over the plywood or off the edge of the table so that you do not cut into the workbenches.** Also, it may be helpful to do a rough cut first (minimizing waste) so that you can maneuver the piece of foam more easily.

Figure 1 shows the end result. Having a perfect circle is not critical, but you should trim off any large errors. You can always make a slightly smaller circle if you mess up the first cut.

Question: What diameter hovercraft base did you decide to use? What was your reasoning?

4.2 Skirt

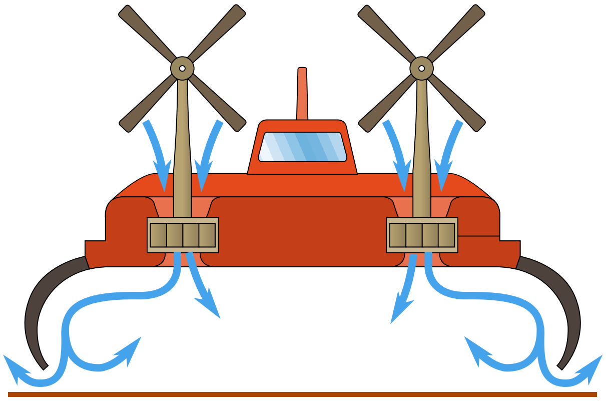

Figure 2: A flexible walled skirt design. Air flows down into the skirt and inflates it. Most air remains inside and recirculates. A small amount of air leaks out and provides the air cushion (Image modified from original on wikipedia.org hovercraft entry).

The skirt is the most critical component of a hovercraft. There are multiple types of skirts including bag skirts, wall skirts, and finger skirts (roughly ranging from easiest to hardest to build). The goal of all skirt designs is to provide a small cushion of air under the hovercraft, while adapting and conforming to any irregularities in the surface. If the surface were perfectly smooth (think about air-hockey tables), you wouldn't need a skirt, you could just pump air under the hovercraft and it would create a nice cushion. In practice most surfaces are somewhat irregular, so the skirt needs to be flexible enough to adapt to the surface, yet strong enough to hold in the air pressure.

A bag skirt is like putting an inner-tube under the hovercraft and putting some holes in it on the bottom. Air flows out of the holes to provide a cushion of air and the inner-tube conforms to the surface. A wall skirt (the type we will be using, shown in Figure 2) is basically a flexible wall going around the hovercraft that keeps the air in and conforms to the surface. A finger skirt consists of large number of small triangular segments and is similar to the wall skirt except it is able to handle a more varied terrain as each segment of the skirt is more flexible and independent of the other segments.

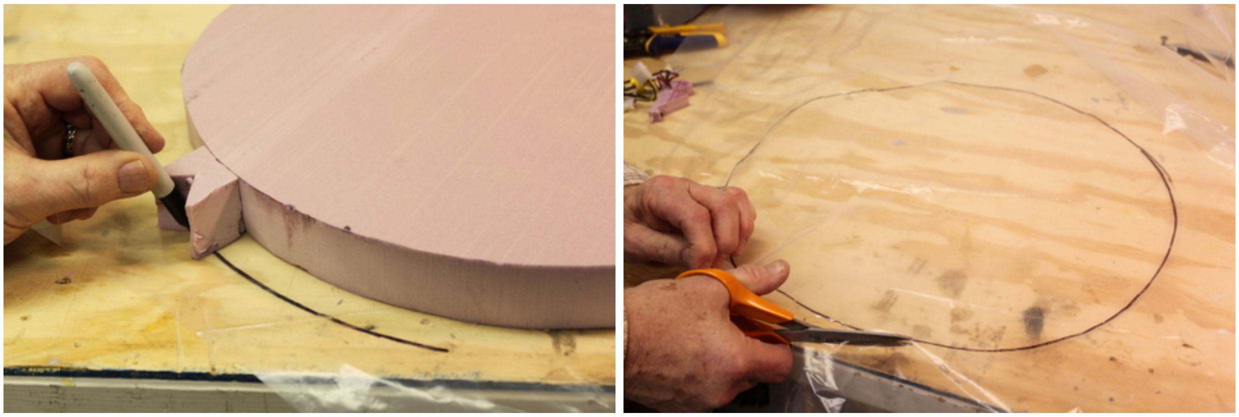

Figure 3: (left) Using a spacer to draw on the plastic. (right) Cutting the plastic.

To construct a wall skirt we will use 5mil plastic sheeting. Through experimentation I found that this particular type and thickness plastic resulted in a good skirt for this size hovercraft. Start by laying the foam you cut on top of the plastic. Create a spacer out of scrap foam to help you guide drawing a circle that is approximately 0.75 inches larger than foam circle as show in Figure 3. Then cut out the plastic circle.

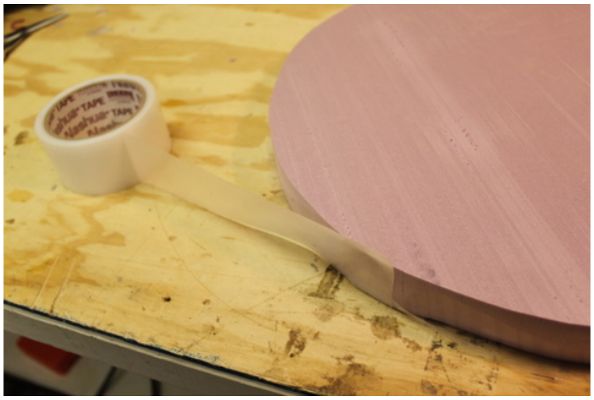

Figure 4: Taping the plastic disk to the hovercraft base.

The next step is to tape the plastic to the bottom of the hovercraft. Place the foam over your plastic cutout and center it. Now, fold up the plastic, it should come about half way up the edge of the foam. As shown in Figure 4, tape the skirt all around the hovercraft. The tape will extend slightly higher than the top of the foam, fold this down all around. Assure that the tape is well adhered to the foam all the way around. The plastic should now completely cover the bottom of the hovercraft. When taping, the plastic does not need to be completely tight to the base, but it should have relatively even tightness all the way around.

The next step is to mark and cut a circle out of the center of the skirt. This will leave a annulus of plastic around the edge of the hovercraft, forming the skirt. Again, create a guide using left over foam as shown in Figure 5. You should size it such that there will be about 1.5 inches of plastic remaining. Then cut out the inner circle. Try to cut smoothly, as this will be the edge of the skirt. Figure 6 shows the resultant skirt.

Note that you may want to experiment with the efficiency of the skirt and lift (described in Section 6) before completing the final thruster layout in the next section. You will, of course, have to install the lift thruster first.

Question: Describe the construction of the skirt and any problems you encountered. Did your first skirt work as expected?

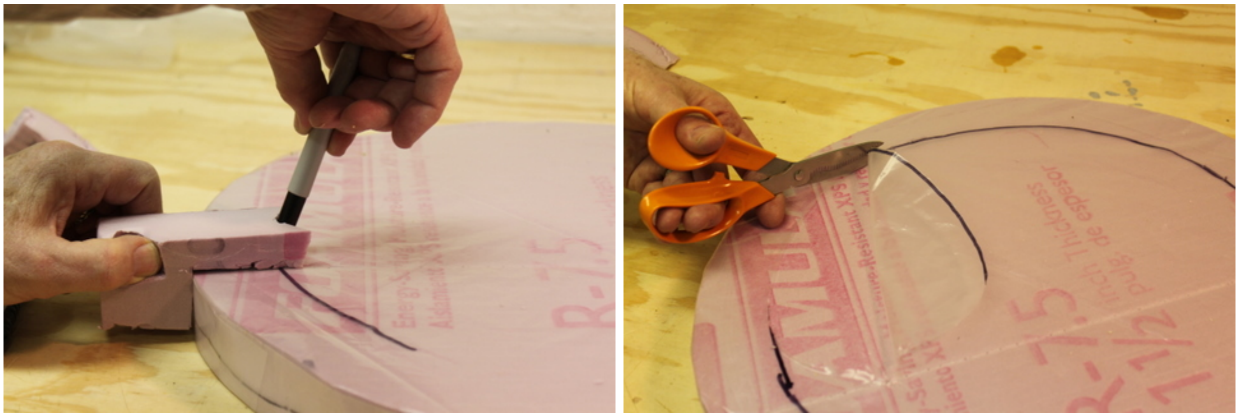

Figure 5: (left) Marking the inside of the plastic with a spacer. (right) Cutting the inside of the plastic to form the skirt.

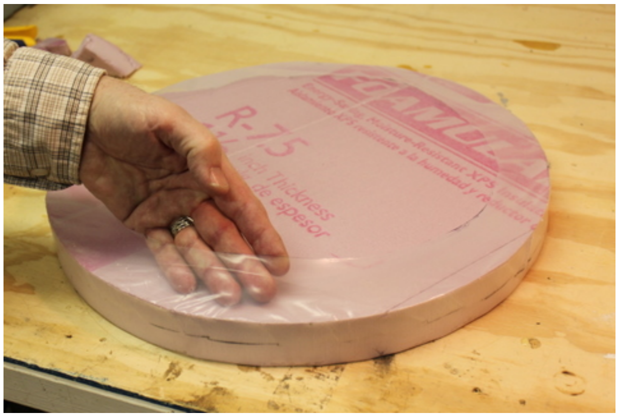

Figure 6: The resulting skirt.

4.3 Thruster Layout

In this section we will come up with a layout for the thrusters. The hoverboard supports a total of six thrusters. One will be used as the lift thruster. The remaining five can be positioned in any configuration.

4.3.1 Lift Thruster

Start by installing the lift thruster. The lift thruster is a brushless motor, which is higher power and lasts longer (it looks different than the rest). The three pin connector should be connected to the 3 pin header that is sticking up by the radio. Note that ground (the black wire) **must** be connected to the pin closest to the bottom of the board. The two pin connector should be connected to the connector between the large wires coming in from the battery. If in doubt, please as the instructor or TA! At this point you should probably verify that you can control the thruster by doing Section 6.

To install your lift thruster, find the center of your hovercraft. Hold the small end of the thruster over the center of the hovercraft. Trace this using a pen or marker and cut out the foam. Note that the hole should be slightly small so that friction will hold the thruster in the hole. It is best to start with a smaller hole, as it is easier to make it larger later[1]. Slide the small end of the thruster into the hole. Now test your

[1] If you do happen to make it too large, you can create another hole in a different location as the lift thruster does not need to be exactly in the center. Cover over your old hole with tape

skirt by powering on your brushless thruster.

4.3.2 Motion Thrusters

You have 5 remaining thrusters to use to control the hovercraft. The layout of these is up to you. However, your hovercraft must be omni-direction (must be able to translate in any direction without needing to rotate first). In addition, you should have rotational control. Note that the thrusters can only operate in one direction (they can only push, not pull).

There are a couple of configurations you can use to achieve omni-directional and rotational control. One idea is to have three translational thrusters (120° separation) and two opposing rotational thrusters. To move in some directions, you will have to use multiple thrusters. You could also use four translational thrusters (±x, ±y) and one rotational thruster. With this configuration you may only be able to rotation in one direction quickly, but you could potentially utilize the torque from the lift thruster to rotate in the other direction. Finally, you could place some of the translational thrusters at a slight angle so they would exert a torque on the craft and produce a rotation. The choice is up to you. It is easy to reconfigure the thrusters, so you can try a variety of setups.

Question: What thruster configuration did you decide to use? Why did you choose this? Include a picture showing your final configuration, make sure to label the thrusters.

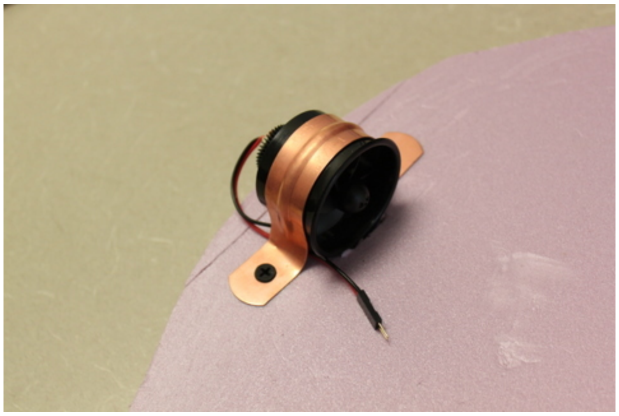

Figure 7: The mounted thruster.

To mount the thrusters we will use 1.5 inch copper pipe hangers and screws as shown in Figure 7. These to not fit exactly, however, you can pliers to form them to the thrusters. You should make sure that they hold the thrusters tight against the hovercraft, but that they do not deform the thruster housing as this will impede the thruster. You can cut a small channel or press the lip of the thruster into the foam to help lock it in place. Use the 1.25 inch drywall screws to secure the bracket. Do not tighten them too much as the foam is soft and you will easily strip the hole. Make sure that each thruster is able to freely rotate by spinning the blade with your finger, just make sure that it is not connected to the hoverboard! If it binds in any location try reshaping your bracket.

Once you have soldered extension wires onto the thrusters (in Section 4.5), you can bury the wires in the foam to keep them out of the way. To do so, cut a small channel in the foam. Place the wires in the channels and then tape over them to keep them inside.

4.4 Mounting the Hoverboard

Before mounting the hoverboard to your hovercraft, we will review some of the major features of the hoverboard. Figure 8 shows a picture of the hoverboard. The main components of the board are labeled. The left side of the board contains the 3.3V processor and all of the 3.3V sensors and peripherals, while the right

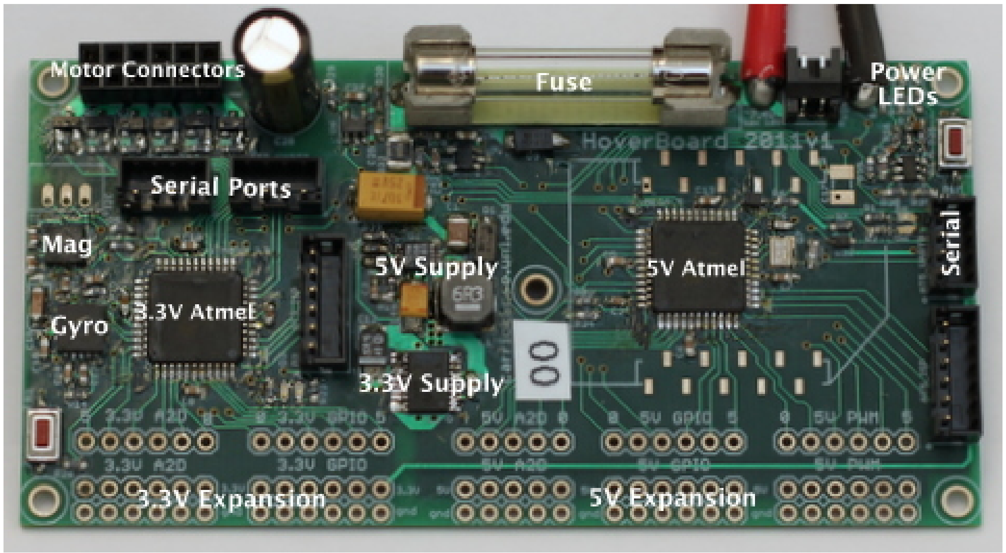

Figure 8: A picture of the hoverboard electronics

side has the 5V processor and peripherals. The bottom edge of the board contains a number of expansion ports that can be used to add sensors and servos to the hoverboard. Again, those on the left side are 3.3V, while on the right side they are 5V. We will not use the expansion ports in this lab, but will in future labs.

At the top left of the board, next to the large capacitor, there is a small daughter board (not shown in the picture) that allows connection of the motors.

At the top of the board, near the center, is a large fuse. This fuse is largely intended to protect the battery from shorts, not the board. This is because the normal operating current for running a couple of motors (5 to 10 amps) is more than enough to burn most things on the board. However, if the power indicator LEDs do not turn on, it is possible that you have blown your fuse (by shorting something or running too many motors at once). Contact the instructor if this occurs.

To the right of the fuse is the power cables and then a set of three power indicator leds. The green LED will be on if power is connected and the battery voltage is good. The yellow and green light will both be on if the battery voltage is below 7.0V. The red and yellow LED turn on, if the battery voltage drops below 6.6V. When the red light is flashing when using the thrusters, it is time to charge your battery. If the red LED is on continuously, the power to the rest of the components on the board is disabled to help prevent the battery from over discharge. If the red LED turns on, you should replace your battery immediately. Note that when the motors are running the yellow and/or red LED may flicker as the resistance in the wires and battery cause a drop in voltage.

Now you will mount the hoverboard onto your hovercraft. Start by choosing a location for your hoverboard. It is possible to adjust the position later, but you should try to minimize the number of times you move it as it will result in additional holes in your hovercraft base.

When choosing a location to mount your hoverboard, consider the location of the battery, how thruster power wires will be routed to connect to the hoverboard, and the weight distribution needed to balance the hoverboard (with the battery weighing significantly more than the hover board). Once you have decided on a position for the hoverboard, simply press the screws down into the foam base. You can remove the hoverboard at any time by just pulling it up. You should be careful when removing and inserting the hoverboard so that you don't enlarge the holes too much. While the fit may be loose, the length of the screws should be sufficient to prevent unwanted motion of the board.

You have also been giving some Velcro. You can use this to affix the battery to the board. If your battery does not have Velcro on it already, please make sure to attach the fuzzy side of the Velcro to the battery.

Question: Where did you mount your hoverboard and battery? Why?

4.5 Soldering Thruster Wires

The wires on the thrusters are too short to reach a single location where the hoverboard will be mounted. You have some thrusters with preexisting extensions, but for the rest, you will need to extend the wires to reach a single location where the hoverboard will be mounted (you may need to shorten some as well). The hoverboard is 2 by 4 inches and the motor connectors are located in one corner of the board. Pick a location for the hoverboard and determine the rough length of the each of the wires needed to reach this location.

Cut the existing thruster wires such that each end of the wires are at least 1 inch long. You will then use the DF-3 2 pin connectors (with wires) to extend the length of the thurster and to have the proper cable. Soldering is an important skill that always comes in useful when working with embedded systems. Remember to "tin" each of the ends of all the wires to ensure a good solder. Tinning is the process of applying solder to the wires.

Now place the tinned wire ends together, perhaps having someone else hold them for you. Heat the wires and apply a little more solder so that they are fully soldered together. Once you have soldered all the joints, have someone else look at them and verify that the look well soldered. Remember that there should be solder over all the wire, there should be significant overlap of the wires, and the solder should be smooth, without sharp points. Once someone else verifies that the joints look good, use electrical tape to tape all of the wires so that nothing is exposed.

It is said that robotics is the "science of cables and connectors." Double check that all connections are good, otherwise you may run into trouble later when a thruster stops working for an unknown reason. It also may be a good idea to test each individual thruster before and after adding the extension to verify that they function.

Everyone in your group should solder at least one thruster.

Once you have soldered all of the wires, you should connect all of the thrusters to the motor connectors on the hoverboard. Make sure that you know the proper orientation to connect the thrusters. If you are unsure, make sure to ask the instructor.

Question: You should decide which thrusters you will connect to which motor input. Which thruster did you connect to which input? It is a good idea to label each wire so you can easily reconnect them in the future when they come undone.

5 ROS (25pts)

In this lab, we will explore the ROS interface to the hovercraft and write code to control the hovercraft using a remote control (you can use either your Arduino one or the xbox controller).

5.1 Computer Setup

You should all have ROS already installed on your computers. You should make sure that you keep copies of your code and anything else on the computer elsewhere. The best option is to setup a source control repository for your code. While this is the recommended option, it is not required for this lab. You can also use a usb stick, space on CSE or UNL shared drives, or other services like Dropbox to backup your code. If your drive crashes it is **not** an excuse to turn in the lab or assignment late. No extensions will be granted.

5.2 ROS Launch Files

Download the sample code from the course website and put it in your ROS workspace. You can then change directories to the sample code directory by typing in the terminal:

```
roscd lab1
```

or alternatively you can manually `cd` to the directory. The command `roscd` is useful, however, because you can use it to go to the source directory for any ROS module. Explore ros a little bit and find out where `roscpp` is.

Question: What is the absolute path of the roscpp module? What does roscpp do?

Next, make sure you are in the lab1 sample code directory. To build the code, run the command rosmake. In the subdirectory launch, there is a launch file called hovercraft.launch. Examine this file.

Question: What ROS nodes are launched by this file?

Before you launch launch this launch file, you need to connect your radio to communicate with the hovercraft. Simply plug in the radio into a usb port on your netbook. You should also connect the battery to your hoverboard at this point.

Question: By examining the launch file, what port/file is the radio located on by default?

To start the ROS nodes that control the hovercraft, run the command:

```
roslaunch launch/hovercraft.launch
```

This will start the roscore and all of the other nodes specified in the launch file. You can kill all of these processes by pressing ctrl+c. If, for some reason, some ROS processes are left running (perhaps you started ROS in some terminal and forgot about it), you can kill all ROS processes by executing:

```
killall python
```

This kills all processes that were started by python, which happens to be all ROS processes, although you should only do this as a last resort (before restarting which is the real last resort) as it could kill other python programs as well.

5.3 rxgraph

Once you have launched the lab1 launch file, run the command rqt_graph in another terminal[2]. This command brings up a GUI that shows different nodes and the messages that they advertise and subscribe to.

Question: What topics are used to control the LEDs? What are their message types?

5.4 rostopic and rosmsg

The command rostopic lets you examine messages that have been advertised and are being published. Use the command rostopic list to show all active message topics. Use rostopic echo to display the output of the gyroscope.

Question: What command did you use to do this? And what information do you get from the output? How fast is this published and how did you determine this?

The command rostopic can also be used to publish messages. Use the command rostopic pub --help to determine how to publish messages, you can also refer to the ROS online tutorials.

Question: Publish a command to toggle the LEDs on the hoverboard. Describe how you figured out how to do this, you can use the command rosmsg to determine parameters for messages.

Question: There are two messages that report the gyroscope[3] data. What is the difference between these messages? What are the units? How did you determine this?

5.5 rqt_plot

The command rqt_plot is a command you can use to quickly visualize and plot values in published message topics. You can plot the gyro data, for instance, by doing:

```
rqt_plot /hovercraft/Gyro/angle,/hovercraft/Gyro/rate
```

[2] ctrl-shift-tab is a useful command in gnome-terminal, as it creates a new tab in the terminal. You will find that you will need lots of terminals open when you are working with ROS. If you use GNU/Linux a lot, you can also try out my favorite terminal multiplexer GNU Screen http://www.gnu.org/s/screen/. Or you can try installing the Ubuntu package terminator, which is a little more mouse friendly.

[3] On startup the gyroscope is calibrated, however, the calibration level changes as the gyroscope heats up. If you notice it drifting significantly you can restart the hovercraft (unplug and then plug in the battery) to cause it to re-calibrate.

If you separate fields by commas they will be plotted on one graph, if you use spaces instead, they will be plotted in different graphs.

Question: What is the maximum rotational rate that the gyroscope can measure? Is it the same for positive and negative rotations? How did you determine this?

5.6 Writing a ROS Joystick Node

We are now going to going to write a new ROS node to control the hovercraft with the xbox controllers, although you can also do the same with your Arduino controllers (which should have the same `joy` interface). Note, you may want to write this node after or concurrently with Section 6.

The ROS node that reads the joystick is called `joy`. You can start this node by running `rosrun joy joy_node`, however, before you do this you may need to start `roscore` if it is not already running.

Question: What messages does the joy node publish? What are the mappings from the different buttons and joysticks on the controller to various joy messages?

We will now create a new ROS node to control the hovercraft using the joystick. Refer to your homework and the online tutorial at `http://www.ros.org/wiki/joy/Tutorials/WritingTeleopNode` for writing a joystick node. However, instead of publishing a `turtlesim/Velocity` message, you should publish a `hovercraft/Thruster` message with the proper values.

For consistency: (1) Use the "start" button on the controller to start and stop the hovercraft; (2) Use the left joystick to control the rotation of the hovercraft; (3) Use the right joystick to control the forward and sideways translation; and (4) Use the red and green buttons to turn on the red and green LEDs when held.

Question: How did you make the "start" button start and stop the hovercraft without rapidly turning on and off when held?

Question: What messages did you connect the joystick node to? Include a picture of the rqt_graph of your configuration and describe why you chose the configuration you did.

6 Hovercraft Experiments (25pts)

Now that you have designed and assembled your hovercraft, it is time to test how well it lifts and moves. Note that you may find that you need to redo your skirt if the performance is not very good. Typical problems include loud vibrations, high friction, or air gushing out of one side or another. Sometimes it is possible to fix these problems by adding or removing weight from the hovercraft or adjusting the balance.

6.1 Powering Thrusters

Note, the thrusters are somewhat inexpensive and I have found that they may die if run consecutively for longer than 10 minutes at a time. Try to limit using the thrusters to times when you actually need to use them. Do not leave them running if you are not actively performing experiments. The symptoms you will see if you do run them for too long are that the thrust output will decrease significantly. I suspect that this is due to motor overheating, although it could be caused by other problems (e.g. worn brushes). Let me know if any of your motors fail and please try to describe the usage characteristics.

You can test the thrusters in a number of ways. The 3.3V Atmel button will run all thrusters except for the lift thruster at a low level. This is a good way to verify that all thrusters are functional [4]. There is also a power supply in the lab that you can use to power a single thruster. Finally, you can manually publish messages to set the thruster power by publishing to the `/hovercraft/Thruster` message, which takes an input between 0.0 (off) to 1.0 (full on). Use this method to test your lift thruster. Warning: there will be a delay between when you start publishing a message and when the hovercraft reacts. This is particularly important when you are trying to stop the thruster, so be prepared to unplug the battery if it gets out of

[4] If a motor output doesn't work at all with different thrusters, it is likely that one of the mosfets on the hoverboard broke, please inform the instructor if this happens.

control. Also, **do not start by setting the thruster to 1.0 as this is way too high, start instead with 0.2**.

Question: What power setting is needed to provide good lift on the lift thruster? Make sure to start at a low value and work your way up. Also, it is important to note that as the battery voltage decreases, you will need to increase thrust to maintain lift.

Question: Report on how well the skirt of your hovercraft works. Did the first version work? If not, what were the problems and how did you overcome them?

Question: **839 Only:** How much weight can your hovercraft support while still being nearly frictionless?

Question: **839 Only:** How much force does it take to move the weighted and unweighted hovercraft? How did you figure this out? Hint: there are pulleys in the common tools box.

6.2 Rotational Experiments

We will now perform some experiments to determine how well the hovercraft rotates.

Question: What is the maximum rotational rate you can achieve?

It is likely that the maximum rotational rate is faster than the gyroscope can measure. Create a new node that limits the rotational thrust to keep it within the measurement accuracy of the gyroscope. Hint: instead of having your joystick node publish directly to the `/hovercraft/Thruster` message, have it publish to another message that this node processes.

Question: How did you limit the maximum rotational rate?

Question: **839 Only:** Perform experiments to characterize the accuracy of the gyroscope. Does the gyroscope drift over time? Does the gyroscope report angles accurately? If you return to the zero angle, does it always end up in the same spot? Report your findings and support them by detailing the experiments you performed. Back up your experiments with tables and graphs as needed.

6.3 Translational Experiments

In this section, we will characterize how well the hovercraft translates in X and Y.

Question: What thrusters do you need to use to translate only along the x-axis? And the y-axis? If it requires using more than one, what is the ratio of thrust you should use?

Question: Derive an equation that allows you to translate along an arbitrary vector (you can also write it in terms translating along a particular angle). What assumptions did you make about the thrusters when coming up with this equation?

Modify the node you created in Section 6.2 to include these equations. Modify the message that this node subscribes to (and that the joystick publishes) to accept X, Y, and rotational messages instead of the individual thruster commands. Each of X, Y, and rotation should take a value between -1.0 and 1.0. This node will then act as an abstraction for the hovercraft so that if you change your thruster configuration, this is the only node that needs to be modified.

Question: Perform an experiment trying to translate along various vectors (perhaps every 45°) using the node you developed above and the equations you derived for translational motion. Describe and analyze the results.

In all likelihood the results were not as good as you may have hoped. Manually calibrate the system to account for the worst errors, although do not spend forever on this.

Question: How did you attempt to fix the problems? How well does the new, manually calibrated, method work? Describe some other ideas that may improve the ability to translate along particular vectors.

7 To Hand In

You should designate one person from your group as the point person for this lab (each person needs to do this at least once over the semester). This person is responsible for organizing and handing in the report, but everyone must contribute to writing the text. You should list all group members and indicate who was the point person on this lab. Your lab should be submitted by handin, `http://cse.unl.edu/~cse439/handin/`, before the start of class on the due date. Include a pdf of your report and your source code in handin. Also make sure to bring in a **printed copy** to class on the due date.

Your lab report should have an introduction and conclusion and address the various questions (highlighted as ***Question:***) throughout the lab in detail. It should be well written and have a logical flow. Including pictures, charts, and graphs may be useful in explaining the results. There is no set page limit, but you should make sure to answer questions in detail and explain how you arrived at your decisions. You are also welcome to add additional insights and material to the lab beyond answering the required questions. The clarity, organization, grammar, and completeness of the report is worth **10 points** of your lab report grade.

In addition to your lab report, you will demonstrate your system and what you accomplished up to this point to the instructor at the beginning of lab on the due date. This is worth **15 points** of your overall lab grade. You do not need to prepare a formal presentation, however, you should plan to discuss and demonstrate what you learned and accomplished in all sections of the lab. This presentation should take around 10 minutes.

Question: Please include your code with the lab report. Note that you will receive deductions if your code is not reasonably well commented. You should comment the code as you write it, do not leave writing comments until the end.

Question: You should make sure to include a picture of your final hovercraft.

Question: Robots like to have names, what are you going to call your hovercraft?

Question: For everyone in your group how many hours did each person spend on this part and the lab in total? Did you divide the work, if so how? Work on everything together? Give details on the hours each group member worked (e.g. keep a list of how many hours per day each person worked and on what).

Question: Please discuss and highlight any areas of this lab that you found unclear or difficult.