Name/NetID:

Teammate/NetID:

Section AB/BB:

**0 1 2 3 4 5 6 7**

**8 9 A B C D E F**

**(circle one)**

# Experiment 10: Navigation

Note: Your TA may allow this lab to continue into next week. Lab 10 was created with this in mind!

## Laboratory Outline

In today's lab, we'll put together all the concepts we've been learning for the last few weeks to create our first autonomous vehicle. We will be incorporating a sensor-controlled PWM circuit as a means of modulating the motor speed on our car. This setup will utilize *feedback* from sensors as a way of keeping the vehicle on track. The first method will make use of our flex sensors as a way of feeling the edge of the table so that the vehicle will drive in a straight line without bumping the edge. Once your vehicle navigates reliably you will, with only minor adjustments to your circuit redo the design to use the Arduino board to control the feedback.

### Learning Objectives

- Learn to extend ideas into your own design project.

### The Engineering Design Algorithm

When an engineer takes on the task of designing a new device, he or she will inherently follow a number of procedures that highlight their skills as effective problem solvers. These skills have been tabulated and are often referred to as the steps of engineering design or, more formally, the Engineering Design Algorithm. We are using an adapted version of that given by Orsak, et. al., in the textbook, The Infinity Project: Engineering Our Digital Future.

The Engineering Design Algorithm:

1. Evaluate the challenge by defining goals and constraints
2. Research the problem to design possible solutions
3. Choose the best solution from the options and build a prototype
4. Test and evaluate the prototype and return to earlier steps as needed

A design report is often as important as the design itself. As you step through the design process, you will make a series of decisions and support these choices within your report.

Notes:

# Curb-Feeling Autonomous Vehicle

In the past several experiments, we developed all the tools necessary to build a car that navigates by feeling the wall next to it. Your task is to develop a design for doing this using the circuits and devices we've learned about in past labs. We will follow the Engineering Design Algorithm here. The challenge is to construct an autonomous, wall-following robot car.

## Goals and Constraints

In many engineering projects, we are limited by what is available to us. In today's design challenge, you have the following parts available for use. You may use any number of them but you cannot use anything that is not on this list.

1) Flex sensor
2) Schmitt trigger inverter
3) 74LS04 Inverter (necessary for driving the motors)
4) Resistors (any resistance you can find in the lab)
5) Magician's chassis (any and all mechanical components)
6) Velcro and any other mechanical materials
7) Redboard (no I/O pins allowed) used only for powering the available parts if needed
8) Protoboard

The car must be able to drive through the corridor that has been built for it without getting stuck. One approach to accomplishing this design is to use the flex sensors to feel the walls of the corridor and adjust the wheel speeds according to how close the wall is to one side of the car. The diagram below depicts an example corridor lay out that your car should be able to navigate.

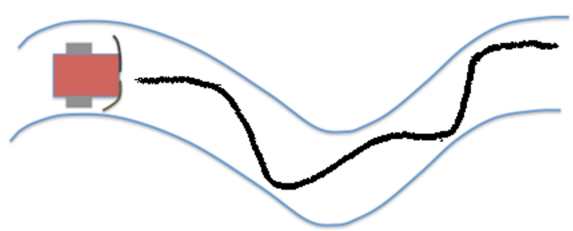


*Figure 1. A curb-feeling (wall-avoiding) autonomous vehicle and its possible path through a tunnel.*

Notes:

## Research and Design

There are many navigation schemes that can be used to accomplish this task. While it is left to you to develop your specific design, you will be given some guidance on how to think about the design.

Each flex sensor acts as an interface with the environment around the car. When a sensor is bent, its resistance changes and we can use this property as a means of detecting if an object is near that side of the car. With this in mind, consider how we want the car to behave. In this particular design challenge, there are only three cases that are important.

*Table 1: Important navigational conditions.*

| | | |
|---|---|---|
| 1 | No walls on either side | The car should drive straight forward |
| 2 | A wall on the left side | Car turns right (left wheel faster than right) |
| 3 | A wall on the right side | Car turns left (right wheel faster than left) |
| 4 | A wall in front | Pick vehicle up and start over |

Previously, you constructed a circuit designed to allow the output of small-signal device to run the motor. Now outputs from the Arduino, a sensor, or other device can be used to turn the motors on and off, and control the speed.

Previously, you also constructed a circuit that produced a pulse-width modulated (PWM) signal based on the state of the flex sensor and you saw how to use this circuit to control the speed of the DC motors.

With all of this in mind, you are now challenged to develop a car that drives through the corridor from end to end without fail. The challenge can be met using the circuits from previous experiments. At a very small scale this problem is like all design projects – you have a goal and some of the pieces or a collaborator willing to build the missing pieces and you have to put them together to make them work. This is a good place to emphasize modular thinking. You have available a sub-circuit that inputs a small current and controls the motors. Also available is a sub-circuit that outputs a square-wave whose duty cycle is determined by the state of the flex sensor. An illustration of how these subcircuits can be connected within a wall following vehicle is illustrated in the figure below.

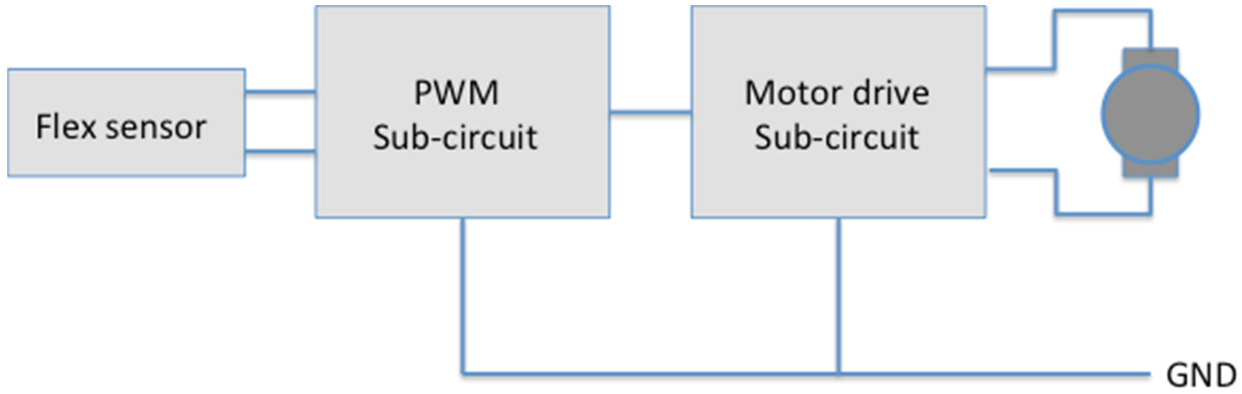



*Figure 1*: Block diagram of one type of autonomous vehicle that utilizes a flex sensor to control a motor. Of course, two such circuits must be constructed to make a complete, operable vehicle.

If the schematics of the sub-circuits are inserted into the figure another level of detail is revealed. For more complex designs it is important to start thinking in terms of sub-circuits and their interfaces. Imagine Microsoft building the PC circuitry from the ground up without thinking of the design in a modular way. From the *research* done in the previous labs you have all the resources needed to construct a wall-following robot. When you have a successful design you will have had to come up with a design solution, then built and tested it. But the design process is iterative and this is only your first time through – how can you add functionality or make it work better. These will be your challenges in the final weeks of the class.

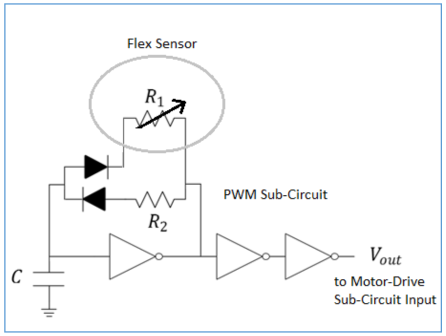
## Prototyping and Iterative Evaluation

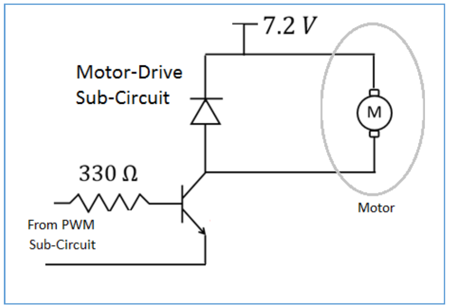
While prototyping you will regularly need to assess and alter your design. Keep a record of each design decision you make. Below are a list of parameters that you will need to consider for in this challenge. Make sure that you keep notes on how you address each of them and include them in your report.

1) The nominal speed of the car under the different conditions listed in table 1
2) How the range of resistance of the sensor maps onto a change in velocity the wheels
3) Where you placed the sensors and why
4) How the feedback works in your design

Please note that this is not a complete list of all things that must be in your report, only a set of topic that are relevant to this specific design challenge.

Notes:



Notes:

# Final Evaluation

Once you have completed and tested your design, demonstrate the functionality to your instructor and get their signature here:

TA signature: ___________________________________________ Date: ______________________

**Report Guidelines**

As a practice for writing your final design report you will document this simple design with a report detailing your design including the design decisions you made during the process. You report should detail each design decision (resistor values, sensor placement, motor speeds, etc.) and the reasoning behind each choice. Be sure to include all measurements and schematics that are relevant to your design (e.g. measured resistance values, PWM waveforms captured from the scope and circuit schematics).

Turn in your report with this page attached at the end to verify that you produced a working demonstration of your design.

Below is a general outline of what things would be found in a good final report. The report should be typed and all figures (graphs and schematics) generated electronically. Please note that the outline shown below provides a recommendation of what things should be found in a report but the order of the sections/subsections does not need to match this outline. The goal of your report should be to provide enough detail about your design and methodology so that another engineer could read your report and duplicate your design (or pick up where you left off).

One report must be submitted by each team of two students. If your design is part of a larger group project, the reports may be submitted as one large document but the separate "team of two" reports must be clearly marked corresponding to its authors. There is no minimum page requirement but a good final report is often around 10 pages long, including figures and a good report for the "Navigation" experiment is expected to be at least 2-3 pages long.

**Suggested Report Outline**

1) **Introduction**

- ***Problem description***

Notes:

For multiple team projects, this should describe the overall project at a high level and the specific portion done by your two person team. This is likely to be similar to the problem description from your proposal but should be updated for changes made to the project since then. Specifically, this should outline what goals your design must accomplish.

- ***Design concept***

Give an overview of your design. This should be at a pretty high level and give a basic idea of how your design accomplishes your goals.
This design concept should include two parts. The first is in regard to the design of some sort of sensor based navigation. The second is the design of some other sensor based functionality of your choosing.

**2) Analysis of Components**

- ***Characterization of each sensor***

Describe each sensor used in your design and what it does.
Include tables of measurements made, the experimental setup used to collect those measurements, and any graphs, linear curve-fits or mathematical characterizations that are relevant to your design.

- ***Design considerations***

Describe the design decisions that resulted from the characterization of your sensors. Did the behavior or sensitivity of the sensor affect where the sensor was placed on the vehicle?

**3) Design Description**

- ***Block diagram***

Hierarchical graphical outline of your design. Each block in the diagram should represent a circuit or device. See Experiment 8 for an example of a block diagram.

- ***Circuit schematics***

Schematics should correspond to blocks in the hierarchical diagram.

If Arduino is used, block diagram of its functionality is required.

Notes:

A qualitative description of the circuit design should be included so that the circuit can be quickly and easily interpreted by the reader. (Please do not simply write a verbal description of how each circuit component is connected to each other component. This is neither useful nor worth any points.)

- **Physical/mechanical construction**

Describe any relevant mechanical aspects of your design, e.g. how each sensor is mounted on the vehicle and where or the method used to mount a given actuator.

*Photographs of your vehicle/project are highly encouraged, especially if those photos are annotated with labels.*

**4) Conclusion**

- ***Lessons learned***

What unexpected obstacles did you encounter in your design process? How did you overcome them? Please note that this should only include lessons learned about your design, not your personal study habits.

- **Self-assessment**
  Make sure to directly address how well your design performed the tasks outlined in your introduction.

# What You Learned

You are now expected to be able to complete a design challenge using sensors feedback to control actuators. There is a strict requirement that all projects utilize some form of sensor feedback control in their design.

# Explore More!

Investigate whether the sensor behavior changes as the supply voltage changes

- Vary the supply voltage from 5V down to 0V and measure the output voltage when over a white and black surface for each voltage level
- Record your data and generate a graph
- Assess whether the sensor's output behaves linearly or not (or over what range of voltages is it linear)

Notes:

# Lab Report Rubric

The following rubric will be provided at the end of each lab procedure. As a final step in preparing your lab report, you will use this rubric to analyze your own performance.

| **Section** | **Criterion** | **Comments:** |
|---|---|---|
| *Experimental Setup and/or Design Description* | Circuit Schematics are drawn neatly, accurately, and properly labeled. Decisions regarding experimental setup and design are clearly explained. | |
| *Measurements* | Tables include units and proper precision. Any *new device* introduced should be characterized using measurements! | |
| *Computations* | Computations performed on raw data are *explicitly* described and follow rules for significant figures. | |
| *Analysis* | Graphs have title, labels, units, scale, legend; Lines for curve-fitting appear in the graph when needed and parameters like the intercepts and the slope are labeled. | |
| *Modeling* | A mathematical model for the curve-fit graph allows for more abstract references to the device's behavior. The expected behavior is explained in the context of the graph. | |
| *Conclusion* | Conclusions are drawn from your experimental results to support the reason(s) for completing the experiment. Closes the loop on the Introduction. | |
| *General Formatting* | Answers to questions clearly labeled. The overall appearance of the report is professional. | |
| *Self-assessment* | This table has been thoughtfully completed. | |