ECE110 Final Group Report

Abstract (Team)

Designing a chassis that is able to leverage multiple sensor inputs without a microcontroller can be a significant challenge. This project explores the development of a robotic chassis with momentary audio triggered reversal along with obstacle detection and avoidance. Through clever logic, we can collect, process, and utilize different sensors' outputs to deterministically control the robot's movement in a simplistic manner. This system utilizes introductory electronic components and builds upon concepts developed in ECE110 alongside information available through sensor and IC datasheets.

Introduction + Plan (Team)

This project aims to build an electric motor car that runs forward by default and goes backward for 10 seconds after it detects a clap and before returning to its forward motion. In addition, to go above and beyond expectations, we will build a detector on the car to prevent the vehicle from crashing into obstacles.

To achieve the design, we will look back on previous labs to utilize electronic components or circuits that could be useful for the completion of this project. After thoroughly understanding the car's requirements, we must provide several solutions to ensure the car functions as we intended. First, we will need a system to control the running of the car's motors, referencing labs 8 and 9, a velocity control system. Second, we need a sensor to detect the sound of a clap so the car knows if someone just clapped, in which case we are using a microphone. Third, a component that takes the signal of the clap as a switch to make the car go backward, a combination of MOSFETs as an h-bridge can achieve this. Fourth, a "timer" system to ensure the car returns to its forward motion after 10 seconds of the clap (an RC circuit with alternating current with a certain duty cycle could be used). Last but not least, a "radar" to detect if there is any object in front of the car so the car can avoid it.

Therefore, we will split the completed circuit of the car into 6 subcircuits: the H-bridge, the microphone, the amplifier, the timed reaction, the speed control, and the ultrasonic sensors. Each member of the group is responsible for the formulation of one or two subcircuits. After the completion of each subcircuit, we will then combine them and form a final circuit for the completion of the motorcar. For the purposes of conciseness, details of the ultrasonic sensor module have been omitted from the report. Details regarding the logic to control the motors have been included; information regarding the functionality of the ultrasonic sensor module can be found in our demo video as well as our overall circuit schematic in Figure 2. Below is a simple schematic of the car.

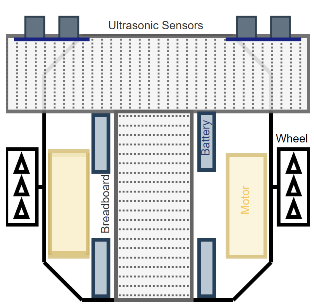


Figure 1. A simple schematics of the chassis

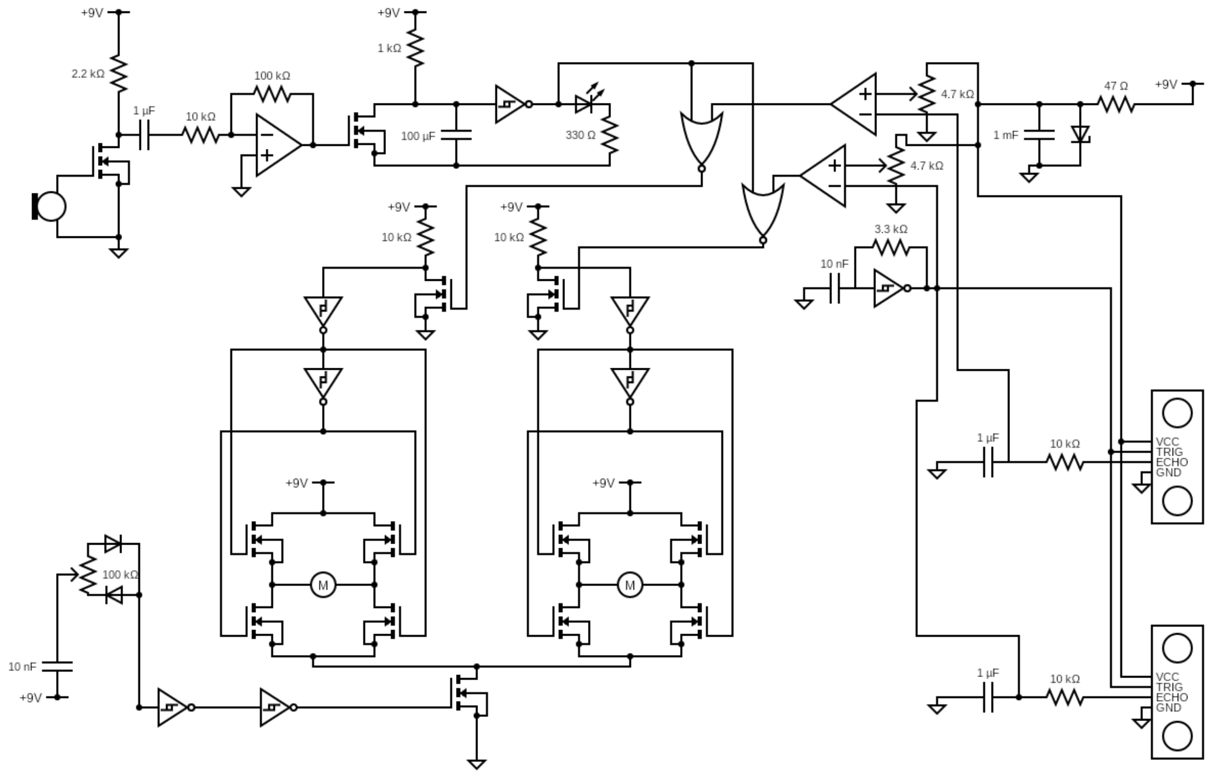


Figure 2. A full circuit schematic for the car

Bidirectional Motor Control with H-Bridge (pola3, nkanchi2)

We first start with a backwards design approach, where we design a circuit to easily change the direction of the motors and then provide deterministic inputs to this circuit to reach a desired outcome. An H-Bridge is a type of system which allows us to electronically control the direction a motor spins through clever gate logic by modifying the direction in which current flows through the motor. We want to use two independent H-Bridges to allow independent control of each motor, to enable turning over strictly forward and backward movement. Thus we have two inputs to this system: V_{LM} and V_{RM}. These inputs control the left and right motors independently and can be inverted through a Schmitt Trigger for the H-Bridge subcircuit.

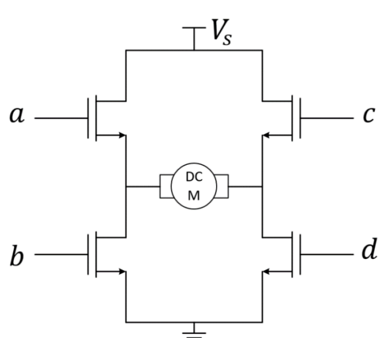


Figure 3: H- Bridge Schematic

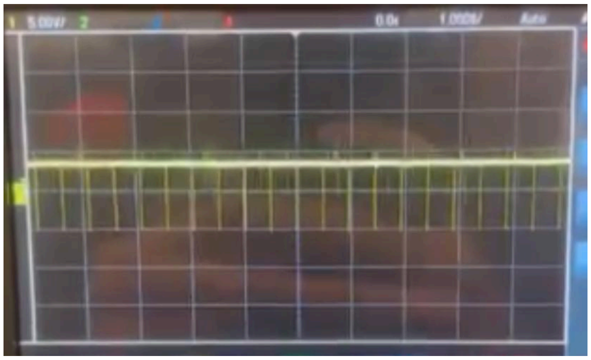


Figure 4: Oscilloscope Reading for Forward Motor

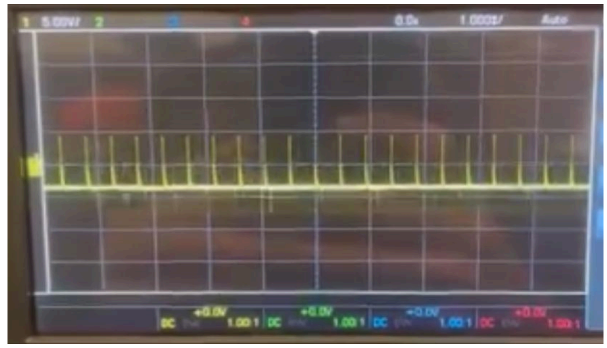


Figure 5: Oscilloscope Reading for Reversed Motor

We can see from the voltage readings that the motors are pulsed with positive or negative voltage depending on what direction the current is flowing through the motor. Figure 4 represents the motor's default operation state with a positive voltage driving the robot forward. We can see in Figure 4, that the motors have a voltage with the opposite sign but equal magnitude, thereby reversing the motor direction as the voltage across the terminals is switched. The pulsing of the motor's voltage can be explained by the speed control subcircuit.

Speed Control with H-Bridge Enable (pola3, nkanchi2)

By adding an Enable gate, we can control the speed of the motors by adjusting the duty cycle in which the motors are enabled. Using the following subcircuit, we can generate an output with a tunable duty cycle. By attaching the enable output with the H-Bridge, we are able to control the speed of the motor through modifying the duty-cycle in which the motor is supplied voltage.

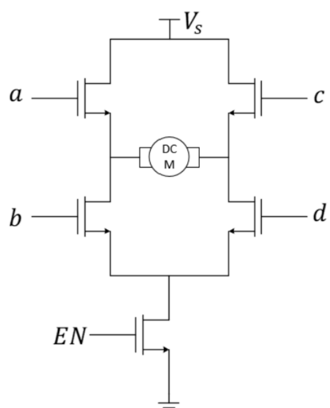


Figure 6: H-Bridge Schematic with Enable

Motor Control Gate Logic (pola3)

Now we can develop a clever solution to controlling the robot through a clap, whilst also having collision detection. We have three sensor inputs: V_{Clap},V_{UL},V_{UR}. These inputs correspond to the signals from the clap detector, the left ultrasonic sensor, and the right ultrasonic sensor respectively. Clapping should take priority in controlling robot movement, followed by collision detection when an obstacle is present. We will utilize a convention in which the output of the motors is reversed when the signal is HIGH(1). We can now set up a truth table to visualize our desired motor outputs based on the input signals.

V_{Clap}	V_{UL}	V_{UR}	V_{LM}	V_{RM}	Commentary
0	0	0	0	0	No clap or obstacle detected -> Move chassis forward
0	0	1	1	0	Obstacle detected to the right -> Turn chassis left to avoid
0	1	0	0	1	Obstacle detected to the left -> Turn chassis right to avoid
0	1	1	1	1	Obstacle detected in front -> Reverse chassis to avoid
1	0	0	1	1	Clap Detected -> Reverse the chassis
1	0	1	1	1	Clap Detected -> Reverse the chassis
1	1	0	1	1	Clap Detected -> Reverse the chassis
1	1	1	1	1	Clap Detected -> Reverse the chassis

From this truth table, we can form the following K-Maps:

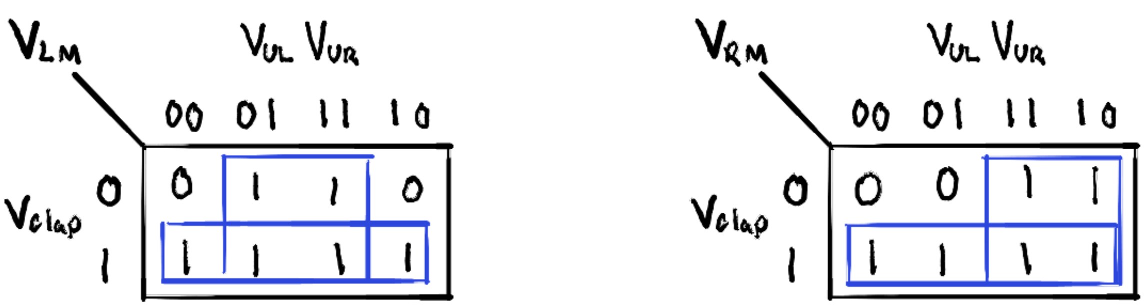


Figure 7: Karnaugh Maps for Deterministic Motor Control Logic

Thus we arrive at the following equations for V_{LM} and V_{RM}:

$\mathbf{V_{LM}=V_{Clap}+V_{UR}}$

$\mathbf{V_{RM}=V_{Clap}+V_{UL}}$

These expressions can be used to deterministically control the motors given inputs from the microphone and ultrasonic sensors. To implement this logic, we plan to use a CD74AC02E Quad NOR IC. While our derived functions for V_{LM} and V_{RM} use OR, we can use a MOSFET-based amplifier to NOT the output of the NOR gate while amplifying the signal, helping us functionally obtain an OR between the desired inputs with an amplified output greater than the IC's V_{dd} of 5V.

Gate Logic Amplifier (pola3)

Having established using the NOR Gate IC to compute the logic, we faced a new issue. The Schmitt Trigger which inverts the signal for the H-bridge has a supply power of 7.5V (9V ideally), while the IC that computes V_{LM} and V_{RM} has a supply power of 5V. When V_{LM} and V_{RM} are low, their inverse from the Schmitt Trigger will be high relative to the Schmitt Trigger (7.5V). However, when V_{LM} and V_{RM} are high (5V), their voltage will be a little lower than the 7.5V, and their inverse will be a little around (1-2V) from our measurements. This uneven standardization causes the motors to spin slower when going in reverse than when going forward. To remedy this, we can amplify the 5V signal to 7.5V to ensure that the Schmitt Trigger has standardized input signals in accordance with the Schmitt Trigger's supplied power. To do this, we can simply use the 5V output of the NOR GATE IC as a gate input to a MOSFET which can then create a connection between the 7.5V power supply and ground, to reach roughly the same voltage. From the schematic in Figure 8, the NOR Gate output is fed in as a gate input on the right. Then, the voltage from the left node after the resistor is sent to the Schmitt Trigger that creates the inputs for the h-bridge that controls the motor.

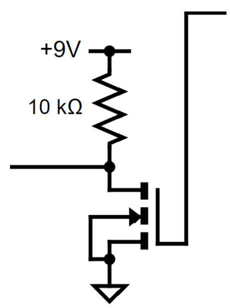


Figure 8: Gate Logic Amplifier Schematic

Microphone-Based Clap Detection Subcircuit (rydert2, src14)

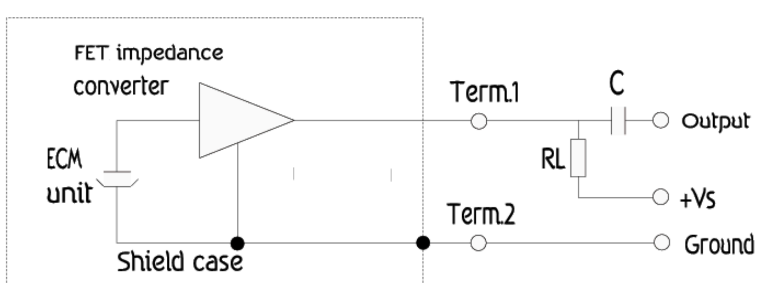


Figure 9: Electret Microphone Clap Detector Schematic

To create a clap detector we will utilize the Electret Condenser Microphone (EM-9745P-46) that's provided in our ECE 110 labkit. Figure 9 is provided by the datasheet of this microphone, the box is a representation of the physical microphone. The internal mechanism of the microphone is hard to explain given the level of the course, however, we only need to know the basic functionality of the microphone when biased with the selected capacitor and resistor given by the datasheet. The microphone acts like an nMOS, when it detects sound the nMOS is on and allows current to flow through the microphone. We chose the recommended resistor of 2.2kOhm and a ceramic capacitor of 1 uF to bias the microphone. As a result of the circuit, when it detects a clap, it outputs an AC voltage signal that only lasts for an instant. Using an oscilloscope to measure the voltage between the output and the ground of the circuit, we found out that although the clap does disrupt the output voltage signal, its magnitude is only around 40 mV (figure 10), which is way lower than what we need to make the car go reversed. Therefore, we need an amplifier to increase this output voltage, which will be explained in the next section.

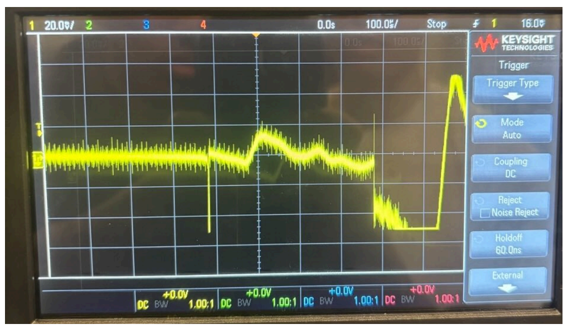


Figure 10: The output voltage of the microphone circuit after the clap

Inverting Operational Amplifier Subcircuit(src14,rydert2)

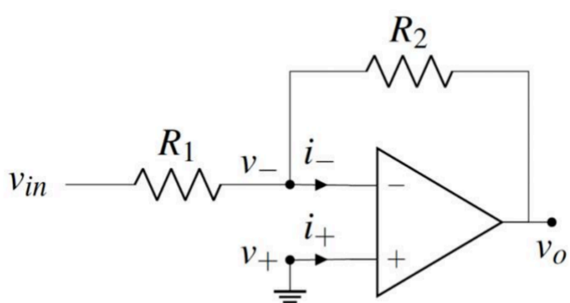
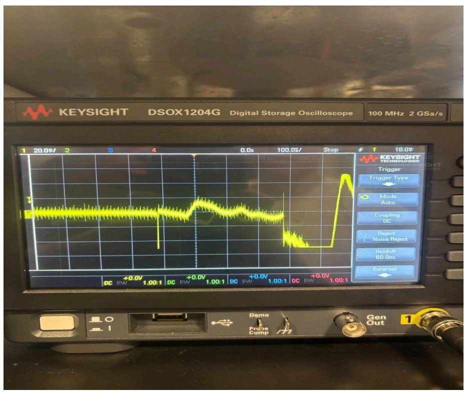


Figure 11: Inverting Operational Amplifier Schematic

The original plan was to connect the output of the microphone to the MOSFET of the timed reaction subcircuit, however, as explained earlier, we came across the issue of the output voltage of the microphone being too low to trigger the nMOS portion of the MOSFET to drain the capacitor. To fix this problem, we introduced an inverting operational amplifier. The operational amplifier (which will now be referred to as the op-amp) is an IC that is responsible for increasing a voltage signal. It uses the properties of KCL to amplify the voltage. No current actually goes into the IC, so by KCL, the current through R1 must be equal to the current in R2, and the circuit is built so that R2 is greater than R1. Since the current is constant but R2 has a higher resistance, by Ohm's Law, there will be a higher voltage across R2, resulting in the gain. This increase in voltage is then sufficient enough to trigger the nMOS portion of the MOSFET, which then allows the timed reaction circuit to drain the capacitor, triggering the inverting input in the H-Bridge resulting in the car successfully moving backwards.

Before Amplifying



After Amplifying

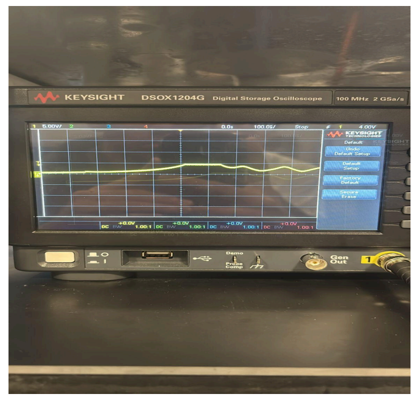


Figure 12: The output voltage of the microphone circuit after the clap

Figure 13: The output voltage of the microphone after amplification

Timed Reaction Subcircuit(nkanchi2)

The goal of the Timed Reaction circuit is to take the amplified mic input of voltage to enable a flip in the H Bridge current direction to rotate the motors of the wheels in the backward direction for approximately ten seconds. The circuit schematic in Figure 13 shows the Time Reaction circuit implemented with the other components of the circuit:

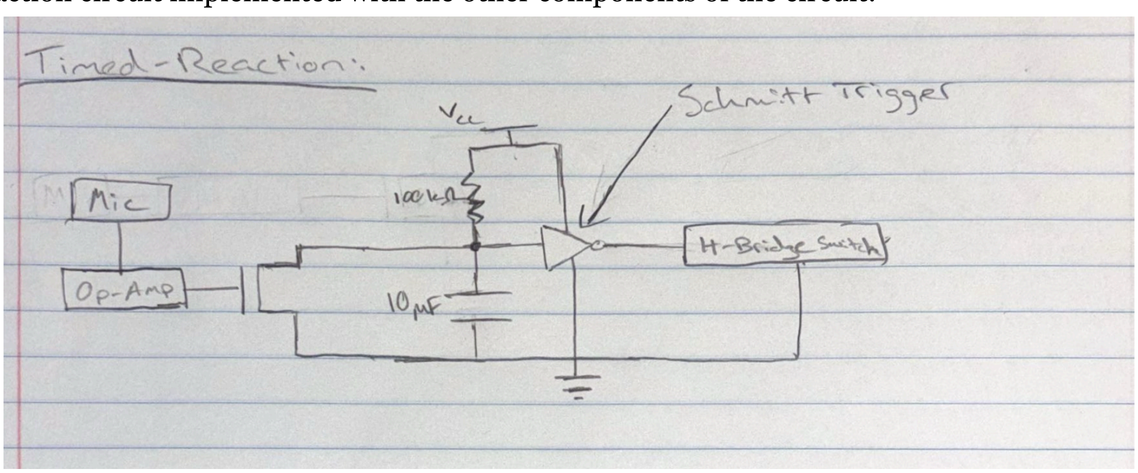


Figure 13: Timed Reaction Schematic

By having the capacitor discharged by the Op-Amp input, the input voltage of the Schmitt trigger will be low and slowly rising, allowing the output voltage to switch the current direction of the H Bridge by powering the ā gates on the MOSFETS that make current go in the opposite direction through the motor. The current direction will go until the capacitor charges enough for the voltage to be in the high region for the Schmitt Trigger input, making the output voltage too low to switch the direction of the motor. The time for the motor to switch directions is dependent on the capacitor charge time, and this can be calculated using the time constant τ = RC. In Figure 11, the calculated time constant is τ = 1 sec, so in order to get the output for the Schmitt Trigger to be high for 10 sec, the capacitor must be replaced with one that is 100 μF.

Before ~10 sec After

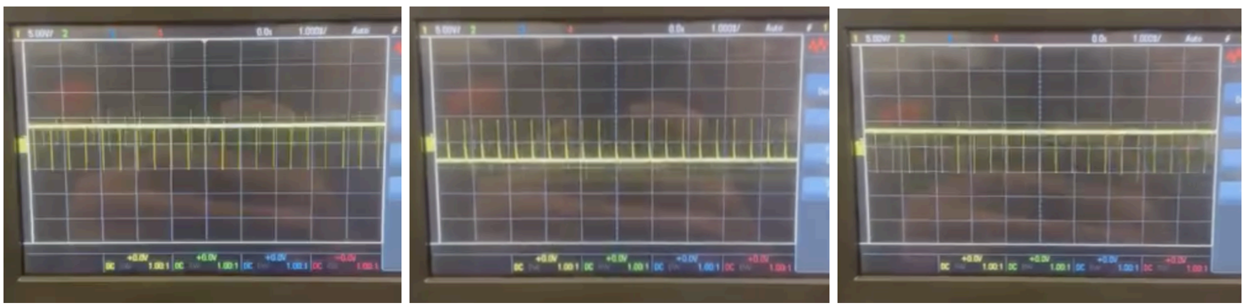


Figure 14: Timed Reaction represented by motor from Figures 4 & 5

Conclusion (Team)

Each subcircuit works collectively with one of the others. To summarize, the speed control system determines the speed of the motor, and the h-bridge and Schmitt Trigger inverter created a logic gate to reverse the motor's running. Then, the microphone and op-amp detect the clap and amplify the output voltage to be sent to the time reaction subcircuit. Next, the car moves in reverse for a time determined by the duty cycle of the time reaction circuit. Finally, the ultrasonic sensor detects spot obstacles in front and sends a signal to the motor to avoid it. Every component in the circuit has its purpose, without any of them, the car wouldn't work as intended. Ultimately, they achieve our goal of building "a motor car with momentary audio-triggered reversal along with obstacle detection and avoidance." Every component in the circuit has its purpose, without any of them, the car wouldn't work as intended.