Grade Conversions {A=100, B=90, C=80, D=70, F=60, ZER0} *Used in Calculating Paper Average Score*

	Students Writing Style (Clarity, Directness, Grammar, Spelling, Style, Format)
	Quality and Level of Technical Content
	Quality of Results and Conclusions
	Quality of Measurements Planned or Taken
	Paper Average Score
	Deductions or Bonus Points (Instructors Discretion)
	Paper Grade

RoverCup Robotics Competition

ECE-3331/301

Project Lab at Texas Tech University

Khisa-Lee Lebrun

Group 7

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Scott Clark, Ph.D., P.E., IEEE

Texas Tech University

Electrical and Computer Engineering Department

Mai 2024

Abstract

This paper describes the design and implementation of the automation of a rover in its task to locate a ball and shoot it in a goal all while staying within a predefined field. All the elements necessary for the result of the project will be discussed including both the software and hardware aspects. Additionally, the requirements proper to this project will be decomposed and analyzed to make sure the demands are met. This document's purpose will mainly be found in the revelation of the steps taken to obtain the definitive and final result for this project.

Acknowledgment

The results shown in the following report would not have been possible without the help and guidance of friends, classmates, and roommates, who provided help, mentorship, and advice. Regarding classmates, extra credit and thanks should be given to my team partner: Wyatt Rust. Additionally, special recognition is extended to all ECE professors, teachers assistants, and especially Rishikesh who took the time to point the project in the right direction and lend out advice while issues were faced along the making of this project. It is crucial to remark that without all this assistance the project would not be where it is currently.

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List of Figures

1. Introduction

In the dynamic robotics landscape, where automation is increasingly in demand in diverse fields such as industry, domestic tasks, and even entertainment, the need for versatile and competent rovers capable of multi-functional tasks is paramount. The design and implementation of an advanced control system designed specifically for the RoverCup Robotics Competition will be described in this paper. In this prestigious competition, the mission is similar to a high-level soccer penalty shoot-out, where the robot will demonstrate its ability to both attack and defend. When adopting an offensive stance, the rover has a clear mission: to quickly detect the target - a regular tennis ball that emits a 1 kHz frequency - and skillfully propel it into the designated goal. On the other hand, in its defensive role, our rover must attempt to thwart any attempt made by the opposite team to score. The stage for this strategic duel spans a tiled arena 12 feet long by 9 feet wide, meticulously delineated by metal tape. Adding to the complexity, infrared beacons positioned at strategic corners of the 6-foot-wide by 6-inch-high goal box, emitting distinct pulses, serve as navigational cues.

2. Body of Technical Report

I- IPS sensors

For this project, the LJ18a3-8 Z/BX proximity inductor sensor [1] was a great safety measure, to ensure that the rover would not get out of the zone. This is one of the most important components of this rover, because getting out of bound would entail disqualification. Positioned in the front, two proximity inductors continuously sense for a line that would denote that the rover is about to get out of the delimitations. The activation of either sensor causes different responses depending on whether the rover is in attacking or defending mode. If the offensive mode is activated and the proximity inductor detects the line, the rover will then begin to go backward for a set period to restart its process to locate the ball to go in the right direction. However, if the rover is in defensive mode, it will back out for a set amount of time before stopping. In terms of electronics, all three IPS sensors typically operate on a voltage range of 6-36 volts DC individually including a ~4mA current draw on each sensor. To provide power to the sensors 9.6 volts were used directly from the battery supply, and an LM339 comparator [2] was used to ensure the longevity of our other components most simply. Using this extra step was crucial because the Basys 3 Artix 7 FPGA Trainer Board [3] used to control the rover can only receive 3.3V, and the use of a comparator ensures that. Below is a circuit diagram that displays exactly how the sensors were connected to implement that system.

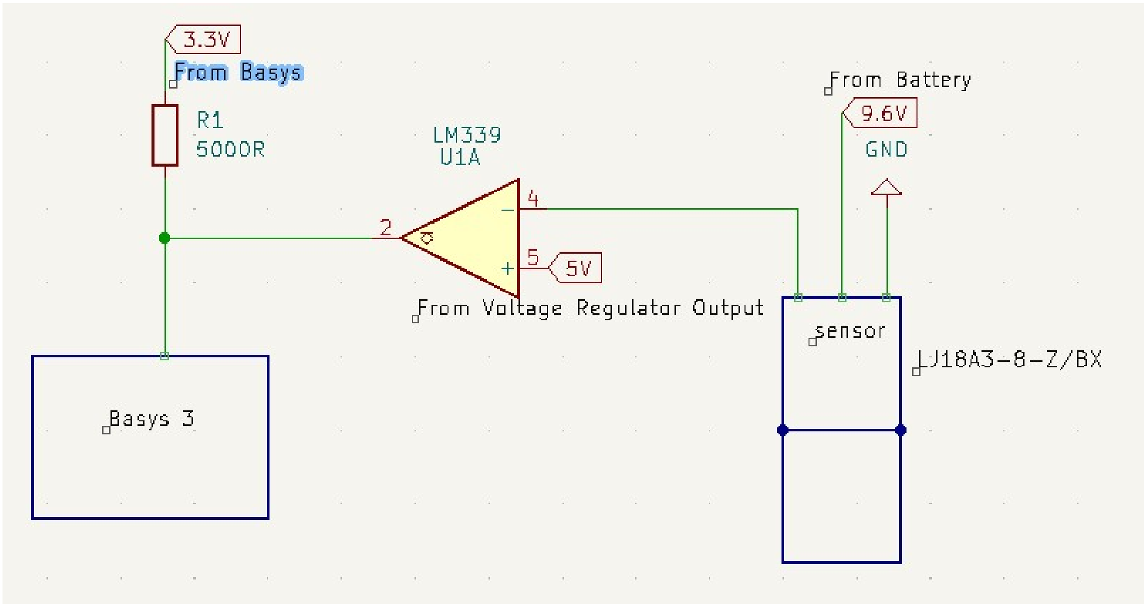


Figure 1: IPS Sensor Circuit

Overall, this system was created to prevent the rover from being out of play and disqualified. It might not be the fastest method, but it is a very safe way to reach the tasks asked. To be located at the front, the sensors will be held by 3D-printed housing that includes holes to mount the sensors allowing them to hover over the floor as seen in the figure below.

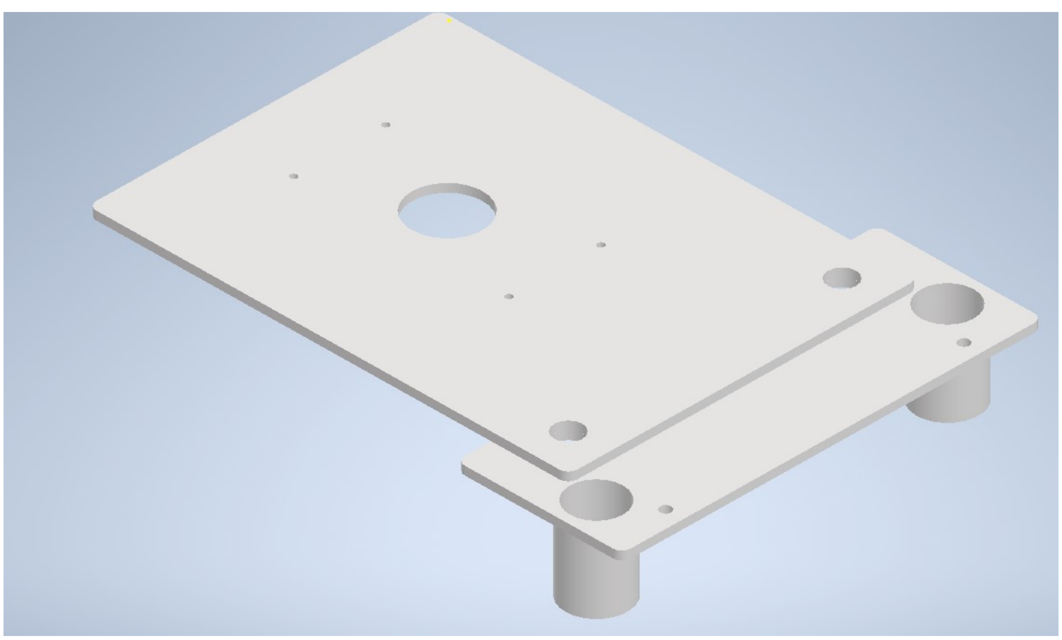


Figure 2: 3D model of IPS mount.

II- Microphones

To be able to shoot the ball, the rover must locate it first. To do so, ICS-40180 MEMS microphones [4] are used to locate a tennis ball that emits a 1 kHz frequency. Using multiple microphones located around the rover allows us to compare the volume detected by each microphone, to then determine the position of the 1 kHz tone. These are connected to the Basys board analog to digital converter (XADC) to use precise measurements and processing of the signals. To convert the audio signal to a signal that can be processed by the rover, the circuit in Figure 3 below shows the process going from the microphones to the Basys board. The physical applications of this circuit can be found in Figure 4 below.

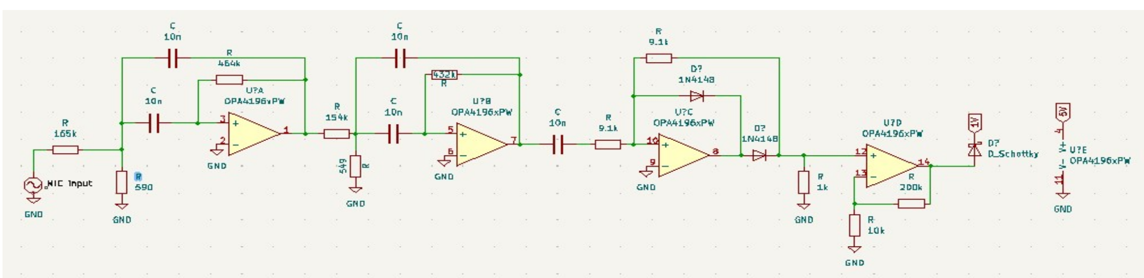


Figure 3: Audio processing circuit.

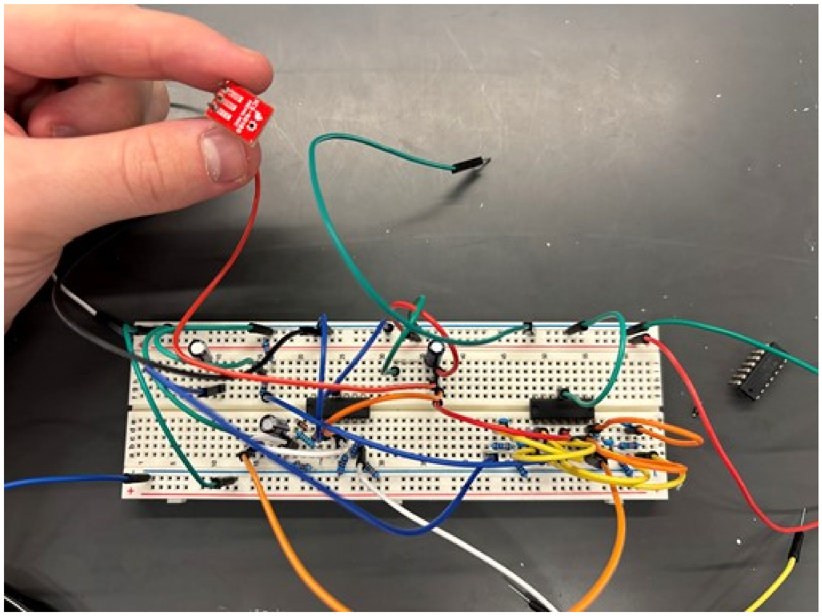


Figure 4: Implementation of audio processing circuit. [5]

It is important to consider the ambient noise so that the rover can focus on the 1 kHz tone. To do so, the signal from each microphone passes through a fourth-order, two-phase Butterworth bandpass filter shown in Figure 5 below that focuses on the filtering part of the audio processing circuit seen in Figure 4 above.

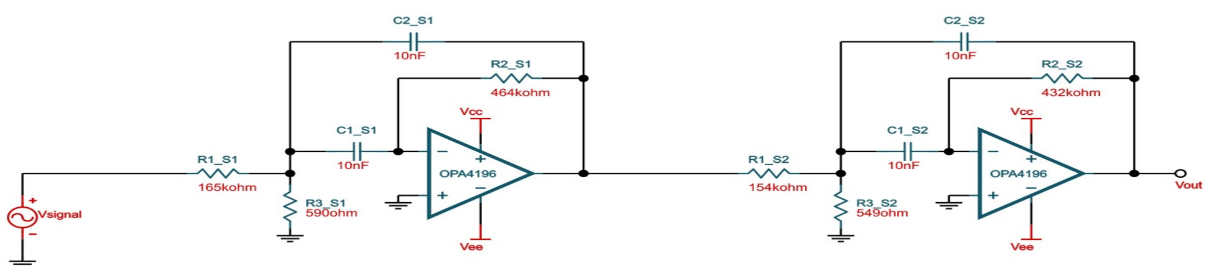


Figure 5: Bandpass filter design. [6]

After being filtered, and before going through to the Basys board, the input goes through an amplifier to make sure that the rover detects only the ball and not its echoes. You can see the circuit used for amplification in Figure 6 below, where the gain is 100.

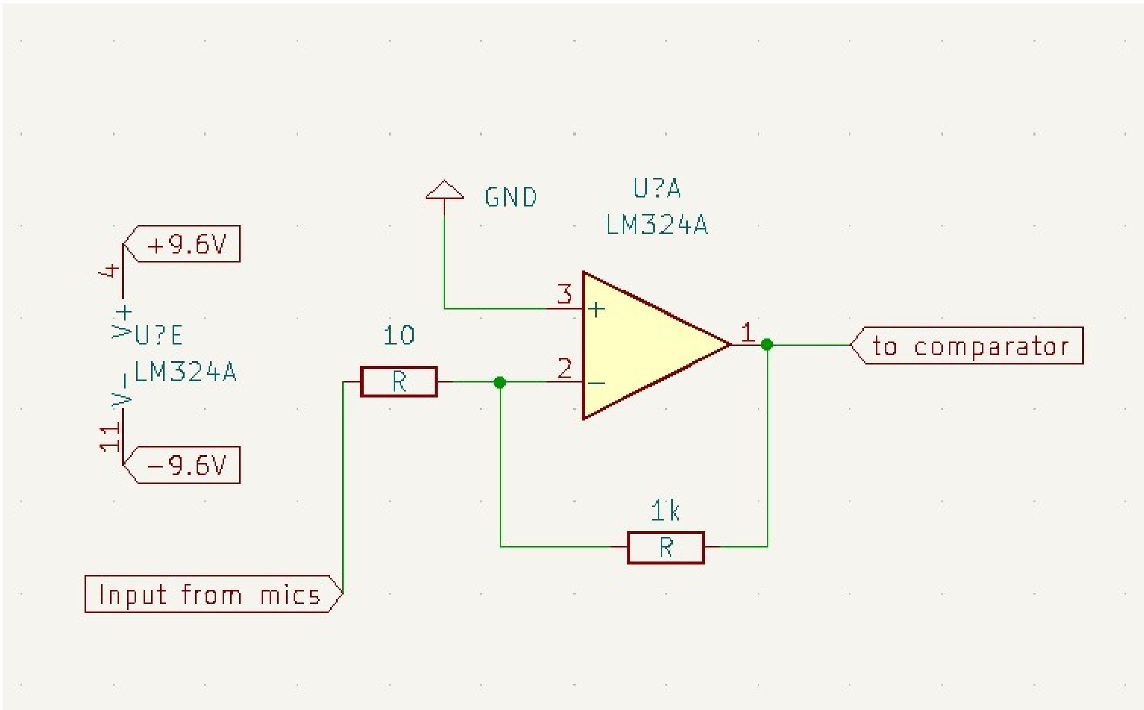


Figure 6: Microphones Amplifiers

The output of the microphone through the filter can be shown in Figure 7 below with a concentration at 1 kHz.

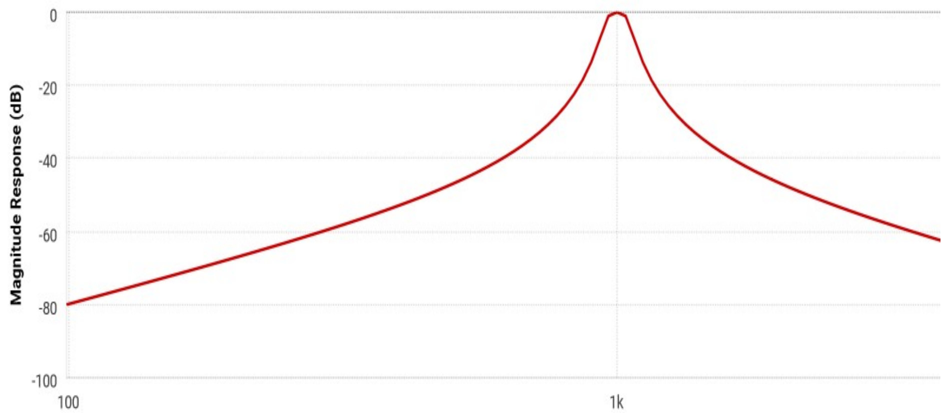


Figure 7: Simulated bandpass filter frequency response. [7]

To make use of the full input range of the XADC (0 to 1 V), a rectifier is used to make the bipolar audio signal unipolar with a half-wave rectifier. The output of the filter and rectifier circuit can be seen in Figure 8. Since the XADC has a 1 mega sample per second limited rate, and the memory microphone output can show irregularities therefore it could lead to missed signals and errors. The use of a 100 uF capacitor in conjunction with the rectifier to convert the voltage to smooth the output to an approximately constant level. The final security for the XADC is a diode connected to a reference voltage to keep the input level within a safe range since the input ports have a maximum safe input voltage of approximately 1.3 V.

Figure 8: Output of filter and rectifier circuit at 1 kHz. [8]

III- IR sensors

As mentioned in the introduction, an important part of this project revolved around the robot's ability to shoot the ball in the goal. The initial direction taken was to make the rover capable of detecting both IR emitters that are placed on each side of the goal, which would lead to the implementation of three IR sensors on the rover. After careful consideration, an alternative route was taken. Building a 10khz bandpass filter was extremely laborious, so in order to prioritize the rapid completion of the robot a system where only the 1khz beacon will be detected was chosen. Once this is located on the left of the goal, the robot will rotate for a fraction of a second before triggering the firing mechanism. This system is effective but not very consistent in terms of detecting the 1kHz IR signal. The rover's final design does not include IR detection, the rover simply rotates to the right for a fraction of a second after obtaining the ball, before launching the ball. As long as, during the offense, the rover could be placed on the far right of the field, the ball would be located in the middle or the left side of the field which would almost ensure a goal.

IV- Directions and motor control

For this project, the Basys 3 Artix – 7 FPGA Trainer Board was the main component when it came to controlling the two DC motors. To control the directionality of the rover, the inputs to the Basys 3 were obtained by testing the H-Bridge with set voltages. Through this, the motor is controlled with the use of signals and pulse width modulation (PWM) that are sent from the Basys 3. The code controlling the motors as seen in Appendix A will be updated to automatically follow directions given by the data collected by the microphones to catch the ball and then the IR sensors to shoot in the goal.

V- Shooting mechanism

Once the robot tracks the ball and reach it, an IR Infrared Obstacle Avoidance Sensor [9] detects that the rover has the tennis ball, signaling to the Basys that it is time to engage the rotation and shooting mechanism. Initially, the shooting mechanism consisted of two servos used as hitters is the simplest and most effective solution as both motors will act as pinball flippers making the shot fast and controllable. This would include the use of two servos. The SG90 Miero Servos[10], as seen in Figure 9 below, can operate on a range of voltage going from 3 V to 6 V and provide 1.8 kg of torque power.

Figure 9: Figure of the SG90 Micro Servo [10]

However, a different and more direction was taken. A slingback shooting mechanism is more powerful and simple, which avoids any issues during the launch of the ball. A servo will be placed under the rover, with its helix glued to a hook that will release the sling back when needed. There will be a hook on the back of the part cupping the ball to be hooked and unhooked from the servo as seen in Figure 10.

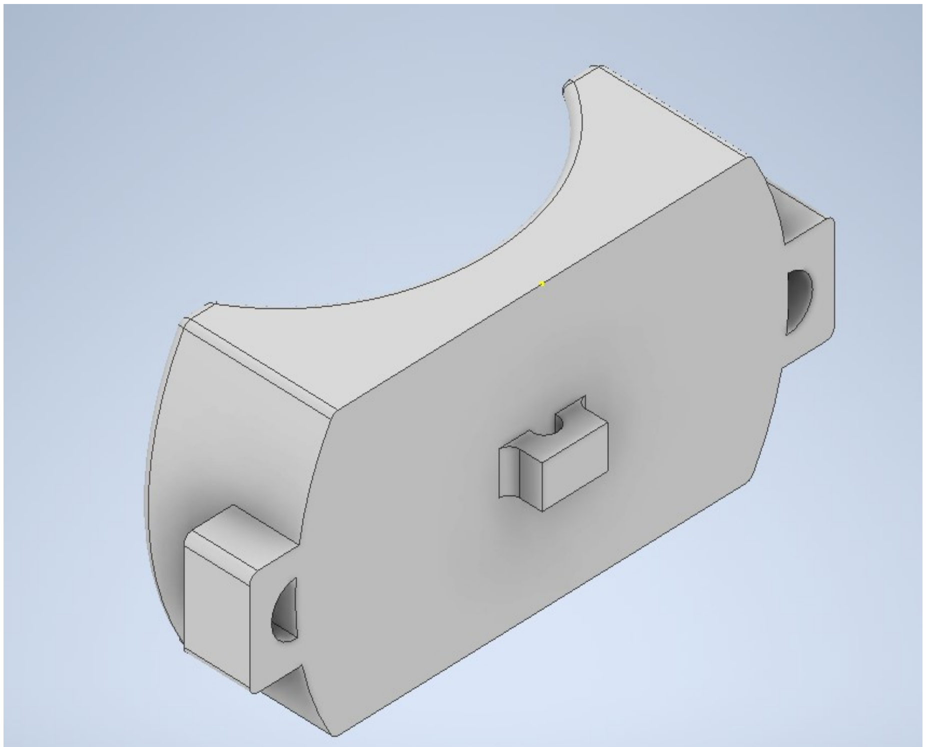


Figure 10: Backside of the Slingback

The sling back holder itself is shaped in a half circle to be able to cup the tennis ball properly and shoot it with enough strength to make it to the goal. This part was 3D printed, see in the Figure 11 below.

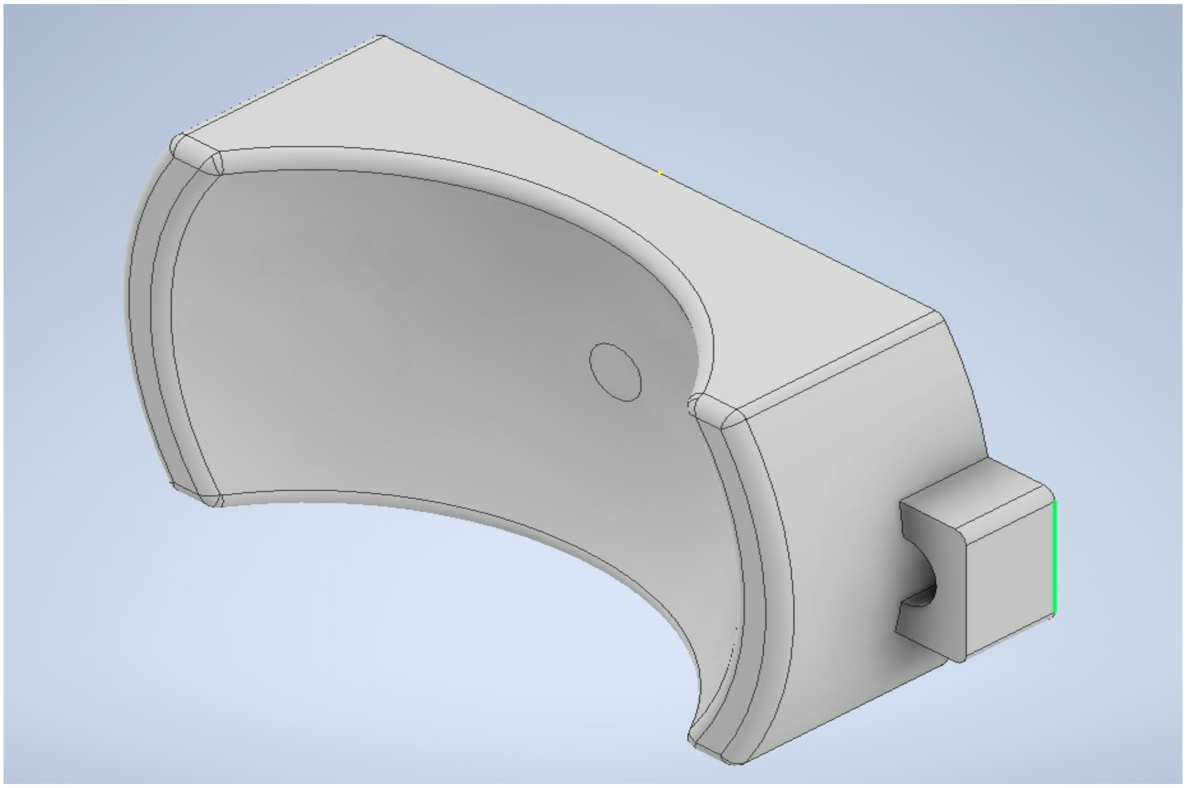


Figure 11: Front of the Slingback

The servos will be placed on the front of the rover and will be triggered once the ball is in its possession. Then once it is sensed through the microphone's system that the ball is in front of the robot the aiming and shooting will take place. Through software, a PWM will control the servo's angle and position, as seen in Appendix B. The different duty cycles will give various angles of the servo to allow for it to be in a "hook" position or a "release" position.

VI- Overcurrent protection and printed circuit board

One of the first steps of the project was to ensure the safety of the parts by implementing an overcurrent protection circuit with a threshold at 1 A. Through the voltage regulator, the voltage is reduced steadily from the 9.6 V given by the battery pack to a stable 5 V that then goes through a voltage division, to output 1V to compare the voltage from the two DC motors one where as long as the motor doesn't draw too much current the comparator will output 3.3 V to the Basys Board. The LM399 quad differential comparator was the comparator picked for this purpose. This way if the voltage coming out of the motor is lower than the reference voltage the comparator is set to low and inversely if the voltage coming out is higher, it will set the output of the comparator to high. Then in addition to a 1A used as hardware protection, through the software overcurrent protection, everything will be shut down in case the output is set to high. The software makes sure the instant surge of current or the inrush to the motor doesn't disable the motor the use of a timer is implemented so that the disabling only happens in the case that the current goes over 1 A continuously for more than 100 ms as seen in the Figure 13 below and the Appendix C.

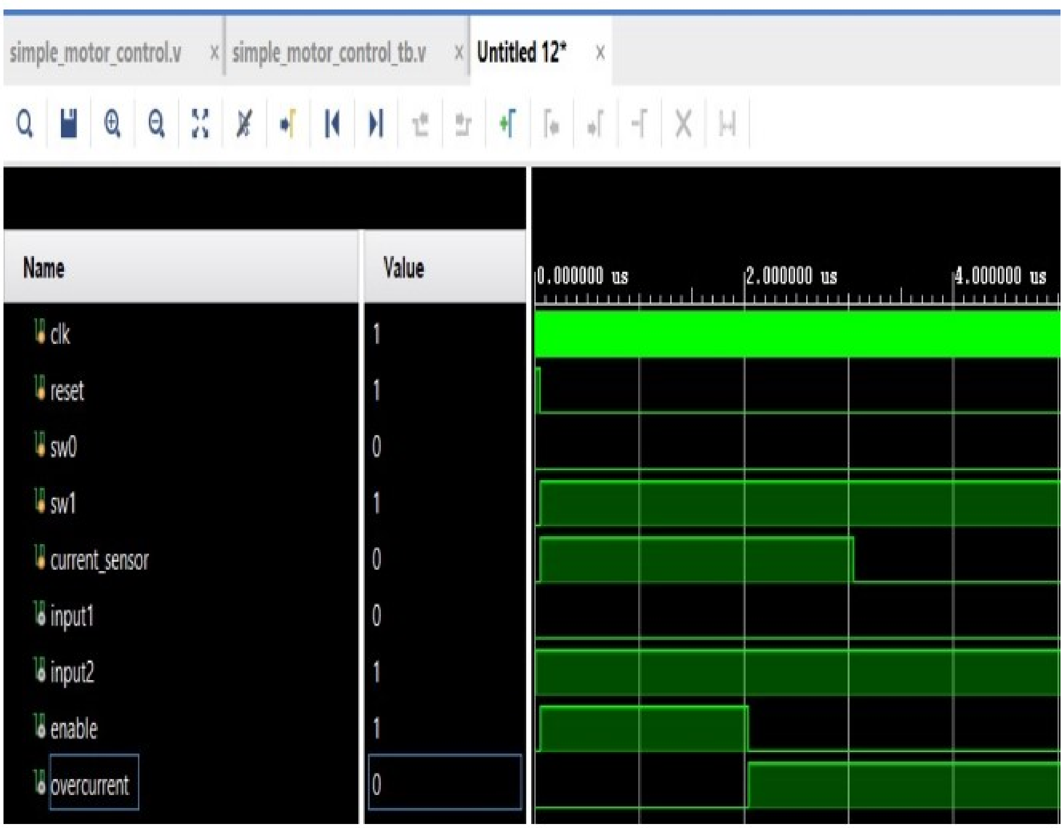


Figure 12: Verilog simulation for the overcurrent protection diagram.

The voltage of 1 V has been picked as the reference voltage because the H-bridge features a 1 Ohm shunt resistor, therefore the cutoff current of 1 A is equivalent to a voltage of 1 V across that shunt resistor. As seen in figures 14 and 15 below, all these different elements have been put into a printed circuit board (PCB) in addition to the pin headers J6 and J8 in the previously mentioned proximity sensors.

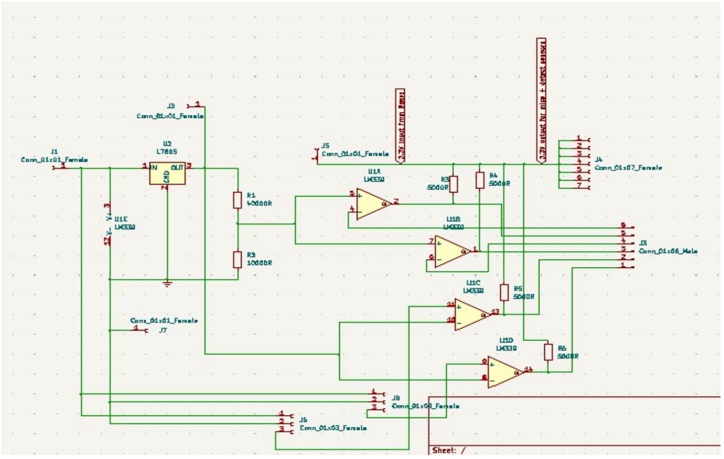


Figure 13: Printed Circuit Board Schematic.

The PCB has dimensions of 40.64 mm by 35.56 mm, which gives enough space for all the components and the tracks while being reasonably sized. The choice to make our board two-layered with a 1.6 thickness made the layout of the tracks easier as they can go from one layer to the other, avoiding any overlaps. More details about the PCB can be found in Appendix D and E. The use of a PCB gives security so that a breadboard doesn't regarding any turbulence the rover might face. However, since the surface mount parts that were supposed to be on the PCB didn't get delivered in time, the use of a solderable protoboard was favored. The schematic is the same as it would have been on the PCB.

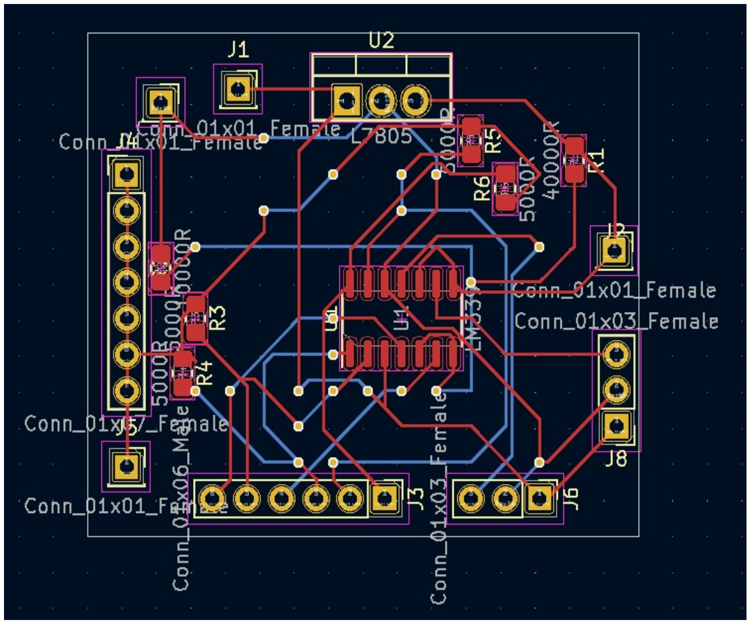


Figure 14: Printed Circuit Board Design.

3. Engineering Standards, Specifications, and Intellectual Property Considerations

In this project, various standards and specifications were followed to ensure quality, and compatibility, and avoid plagiarism. For programming and debugging, tools such as multimeters, function generators, oscilloscopes, and Verilog simulation software were used. Specifically, we used Xilinx Vivado, version 2021.2, for FPGA design on the Basys 3 Artix-7 board. This ensured compliance with industry standards and compatibility with existing products using the same protocols. The exclusive use of Verilog simulation and Vivado minimized the risk of conflicts with other proprietary technologies.

4. Safety, Public Health, and Welfare Considerations

Safety, health, and well-being are key considerations of the project. Great importance is attached to observing safety rules in the laboratory, particularly the wear of appropriate personal protective equipment (PPE) such as goggles and gloves. Additionally, protective, and appropriate outfits are just as important in the laboratory. During soldering, extra steps are taken to make sure to work in a well-ventilated environment to avoid inhaling toxic fumes. In addition to the use of appropriate tools and equipment to minimize the risk of injury and burns. After each use, a careful cleanup of work areas is done to ensure the safe and proper handling of waste to prevent environmental contamination. By implementing these rigorous safety procedures, a safe working environment is ensured, while minimizing health risks and preserving general well-being.

5. Global, Cultural, Social, Environmental, and Economic Factor Considerations

In this project for the Project Laboratory I course at Texas Tech University a strong emphasis is put on sustainability and efficiency. Integrating an overcurrent protection circuit into the design not only protects the motor from potential damage due to excessive currents but also contributes to the project's ecological profile. Reducing the risk of motor overheating aims to extend the rover's lifespan, minimizing electronic waste and promoting resource conservation. The use of fuses protects the more expensive parts of the project such as the motor on the rover at a lower cost. Parts like the rover or the Basys board are important to protect as they total to 234.92 USD, see Appendix F. The use of a PCB instead of multiple breadboards ensures that various cables won't come in contact, creating unwanted shorts that could also create damage to the more costly parts. This mindful approach underlines a strong commitment to responsible engineering practices.

6.Conclusion

In conclusion, this project represents a significant advance in the field of robotics, demonstrating the ability to design and implement an advanced control system to meet the requirements of the RoverCup robotics competition. Through the use of inductive proximity sensors, infrared sensors, and MEMS microphones, the rover has been equipped not only to detect the ball and aim accurately at the goal but also to defend effectively against opposing attempts. The integration of these components has enabled the development of a robust and reliable system, with safety mechanisms such as overcurrent protection, guaranteeing the rover's smooth operation in a variety of conditions. In addition, the design of a customized printed circuit board offers a compact and durable solution for integrating the various system elements. Thanks to a methodical approach and effective collaboration, every aspect of the project is carefully studied and implemented and will in a rover capable of successfully playing both offense and defense in the RoverCup competition. These results highlight the continuing advances in the field of robotics and open new possibilities for innovation and improved robot performance in dynamic and demanding environments.

7.References

[1] the LJ18a3-8 Z/BX Proximity Inductor datasheet

https://geeksvalley.com/wp-content/uploads/2021/06/Proximity-Switch-LJ18A3-8-Z-BX.pdf

[2] Texas Instrument LM339 Data Sheet

https://www.ti.com/lit/ds/symlink/lm339.pdf?ts=1708278175084&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FLM339%253Futm_source%253Dgoogle%2526utm_medium%253Dcpc%2526utm_campaign%253Dascamps-null-44700045336317113_prodfolderdynamic-cpc-pdf-googlewwe_int%2526utm_content%253Dprodfolddynamic%2526ds_k%253DDYNAMIC%2BSEARCH%2BADS%2526DCM%253Dyes%2526gad_source%253D1%2526gclid%253DCjwKCAiA8sauBhB3EiwAruTRJm_x2xX_hYRz8AFMfMPlHelDgXlJpp84ttW9Bweh0PbgBGhHs5YYBoC6IMQAvD_BwE %2526gclsrc%253Daw.ds

[3] Basys 3 Artix 7 FPGA Trainer Board

https://digilent.com/shop/basys-3-artix-7-fpga-trainerboardrecommendedforintroductoryusers/?utm_source=google&utm_medium=cpc&utm_campaign=20999384625&utm_content=160333492044&utm_term=basys3&gad_source=1&gclid=CjwKCAiA8sauBhB3EiwAruTRJlE5KZ6lZGpVq5lNpFPotRAbN72EvKUKoED2e8JeUDGnikchgdZURoCfm0QAvD_BwE

[4] ICS-40180 MEMS microphones datasheet

https://cdn.sparkfun.com/assets/8/e/7/e/b/DS-000021-v1.22.pdf

[5] Image implementation of audio processing circuit taken by Wyatt Rust

[6] Butterworth filter

https://radiouniversidad.ujcm.edu.pe/4th-order-low-pass-filter-k.html

[7] Simulation band pass filter frequency response ran by Wyatt Rust

[8] Image of the output of the filter and rectifier circuit at 1 kHz taken by Wyatt Rust

[9] IR detector

https://www.amazon.com/Infrared-Avoidance-Transmitting-Receiving-Photoelectric/dp/B07PFCC76N/ref=asc_df_B07PFCC76N/?tag=hyprod-20&linkCode=df0&hvadid=693071814664&hvpos=&hvnetw=g&hvrand=7466189017098091155&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9028540&hvtargid=pla-2003305092407&mcid=9803be811986359f92a57c1be91cb750&gad_source=1&gclid=Cj0KCQjw0MexBhD3ARIsAEI3WHKvmu8-kNRKWOiUdyCdww-FHzRUCbhgEG3okeGH3HNiYlbUm7_4ezEaArI3EALw_wcB&th=1

[10] SG90 Micro Servo datasheet

https://components101.com/motors/servo-motor-basics-pinout-datasheet

[13] H-Bridge to DC Motor Connection

https://itp.nyu.edu/physcomp/labs/motors-and-transistors/dc-motor-control-usingan-h-bridge/

8.Appendices

Appendix A: Verilog Code for Motor Control

This section provides the code snippet that outputs the PWM that controls the motor.

```

initial begin
    counter = 0;
    input1 = 0;
    input2 = 0;
    enable = 0;
    switch_values = 0;
    duty_cycle = 0;
    overcurrent = 0;
    current_direction = 0;
    overcurrent_counter = 0;
    current_sensor_out = 0;
end

//actual clk is 100 MHz? at pwm frequency of 100 Hz:
//1000000 clock cycles per pwm period

always @(sw0) begin
    duty_cycle = 0; //prevent change in direction while signal is high?
    // input1 high and input2 low -> forward
    // input1 low and input2 high -> reverse
    current_direction = sw0;
    input1 = sw0;
    input2 = ~sw0;
end
```

In summary, this Verilog snippet implements a basic PWM (Pulse Width Modulation) control scheme based on a switching input (sw0). It is used to determine the direction of the motor (forward or reverse) according to the value of the commutation. The duty cycle is set to zero to ensure that there is no change of direction when the signal is high. A clock frequency of 100 MHz and a PWM frequency of 100 Hz are assumed, which means that there are 1,000,000 clock cycles per PWM period.

Appendix B: Verilog Code for Software-Based Control of the Shooting Mechanism.

This section provides a code snippet that displays the control of the two servos used to shoot the ball into the goal.

```verilog

module Servo_Control(
    input clk,      // Clock input
    input [7:0] sw,  // Input switch
    output signal//LED0       // Output PWM signal
);

reg [20:0] counter = 0; // 2^21 counter later divided
reg [17:0] width;
reg temp_PWM;
reg [17:0] tempwidth = 0;

always @(posedge clk) begin
    if (counter >= 200000000) begin
        counter = 0;
    end else begin
        counter <= counter + 1;
        end
        if (width > tempwidth)
            tempwidth = tempwidth +1;
        else
            tempwidth = tempwidth -1;

        if (counter > tempwidth) begin
            temp_PWM <= 1;
        end else begin
            temp_PWM <= 0;
    end
    end

```

In summary, this Verilog snippet of code controls a logic for the shooting mechanism, using once again a clock (clk) and a reset signal. The servos go from their neutral position to their shooting position according to the rising edge of the clock. Later this code will be implemented with the sensing of the microphones, detecting the position of the ball. Making the shooting happen once the ball is in the rover's possession.

Appendix C: Verilog Code for Software-based Overcurrent Protection.

This section provides a code snippet that protects the parts from a current over 1 A being drawn by the motor.

```
always @(posedge clk) begin
    current_sensor_out = current_sensor;
    if(current_sensor) begin
        if(overcurrent_counter < 10000000) begin
            overcurrent_counter = overcurrent_counter + 1;
        end
    end else begin
        overcurrent_counter = 0;
    end

    if(overcurrent_counter >= 1000000)
        overcurrent = 1;

    if(reset)
        overcurrent = 0;

    if(!overcurrent) begin
        switch_values = {sw3, sw2, sw1};
        duty_cycle = switch_values;
        counter = counter+1;
        if(counter < (duty_cycle*1000000)/8)
            enable = 1;
        else if(counter < 1000000)
            enable = 0;
        else
            counter = 0;
    end else
        enable = 0;
end

endmodule
```

In summary, this Verilog snippet of code controls logic for a system, using a clock (clk) and a reset signal. At each rising edge of the clock, the current sensor is read and used to 20 detect excessive current. If excessive current is detected over an extended period (10 million clock cycles), the overcurrent flag is set. This flag is disabled when a reset signal is received. If no overcurrent is detected, the switch values (sw1, sw2, sw3) are read and used to define the duty cycle. Depending on the duty cycle, a counter is incremented and the enable state is determined to control the system.

Appendix D: Details of PCB

This section provides additional information regarding the PCB manufacturing details.

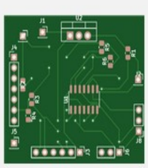
Gerber file:	Updated Final final PCB_Y1	Build Time:	2 days
Base Material:	FR-4	Layers:	2
Dimension:	40.64 mm* 35.56 mm	PCB Qty:	5
Product Type:	Industrial/Consumer electronics	Different Design:	1
Delivery Format:	Single PCB	PCB Thickness:	1.6
Impedance Control:	no	Layer Sequence:	
PCB Color:	Green	Silkscreen:	White
Material Type:	FR4-Standard TG 135-140	Via Covering:	Tented
Surface Finish:	HASL(with lead)	Deburring/Edge rounding:	No
Outer Copper Weight:	1 oz	Gold Fingers:	No
Flying Probe Test:	Fully Test	Castellated Holes:	no
Edge Plating:	No	Remove Order Number:	No
4-Wire Kelvin Test:	No	Paper between PCBs:	No
Appearance Quality:	IPC Class 2 Standard	Confirm Production file:	No
Silkscreen Technology:	Ink-jet/Screen Printing Silkscreen	Package Box:	With JLCPCB logo
Board Outline Tolerance:	±0.2mm(Regular)		

In summary, this is an in-depth detailed description of the PCB that offers information mainly about the shape of the board as well as the material used and some technical details.

Appendix E: Confirmation of order for the PCB

This section provides proof that the PCB has been ordered and will be delivered before the demonstration day.

2024-03-23 | W202403232322492



PCB Prototype

Order #:Y1-7553519A

Build Time:2 days

5pcs $2.00

Product Details

Updated Final final PCB_Y1

Production Progress

Merchandise Total:$2.00

Shipping Charge:$7.80

Sales Tax:$0.81

Order Total:$10.61

In Production

The order cannot be cancelled once it has been put into production.

In summary, this confirmation of order proves that the PCB had been ordered within the delay while showing that it will arrive on time.

Appendix F: Material Cost Budget

This section provides the budget for the project

Name	Cost	quantity	notes/website	purchase date	total		TOTAL
rover 5 robot chassis	$41.95	1	Amazon.com	1/24/2024	$41.95		$258.92
H-bridge	$4.67	1	TTU ECE Department	1/24/2024	$4.67		
AA batteries	$0.55	6	AA anystore	1/24/2024	$3.30		
Basys 3 Artix-7 FPGA	$165.00	1	Digilent.com	1/24/2024	$165.00		
Bread Board Starter Kit	$11.00	1	Amazon.com	1/29/2024	$11.00		
Proto Board	$9.00	1	stock room	2/4/2024	$9.00		
Omni-Directional Mic	$3.00	4	stock room	2/17/2024	$12.00		
IR sensor	$1.00	2	stock room	2/17/2024	$2.00		
PCB	$2.00	5	Amazon.com	3/20/2024	$10.00		

In summary, this diagram describes the price of each element purchased for the project. The elements listed range from expensive elements such as the Basys 3 Board to simpler elements like the cables included in the Bread Board Starter Kit or the PCBs.