CRITICAL DESIGN REVIEW

SENIOR DESIGN II – GROUP 13

CHRIS BROWN

ELECTRICAL ENGINEERING

MIKAELLA PENAGOS

ELECTRICAL ENGINEERING

RYAN BORI

COMPUTER ENGINEERING

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ELECTRICAL ENGINEERING

MOTIVATION/BACKGROUND

"Aqua Strings" Interactive Water Harp

- Resembles the musical instrument with water as strings

Applications

- Entertainment – System encapsulates a visual fountain aesthetic while with user interaction
- Accessibility – Impaired or disabled users can play music without needing the motor skills of physically plucking a string

Current Project Model

"Journey of Water" at Epcot

GOALS/OBJECTIVES

- Basic Goals
  - Create 3 fully-functioning strings of water that correspond with 3 individual tones
  - Construct an interactive instrument with multiple sensors to read user input and translate to a sound or note output
  - Implementation a real time signal processing system to achieve responsive reactions with minimum latency
  - Maintain a continuous water flow so there is no undesired break in the water column
- Advanced Goals
  - Create 5 fully-functioning strings of water that correspond with 5 individual tones
  - Include a mode switch consisting of OFF, FOUNTAIN, and HARP
- Stretch Goals
  - Create 8 fully-functioning strings of water that correspond with 8 individual tones
  - Have audio options with different electronic sounds so the user can control
  - Install horizontal lasers to play specific tones based on the vertical height of hand

TABLE OF ENGINEERING SPECIFICATIONS

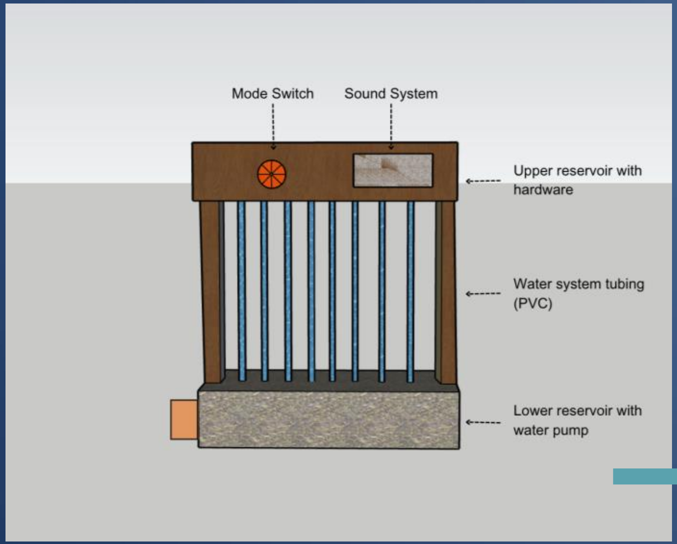
Table 2.5.1: *Engineering Specifications Table*

Component(s)	Parameter	Specifications
Photoresistor	Detection Time	< 10 ms
Photoresistor, MCU, Speaker	Response Time	< 100 ms
Water Pump, Level Sensors	Water Level Maintenance	< 2 in of water
Laser	Wavelength	650 nm (Red)
Laser	Power	< 5mW
Pump	Flow Rate	2.3 gallons / minute
Pump	Lift Height	< 1.5 m
Reservoirs (Upper/Lower)	Capacity	2 gallons each

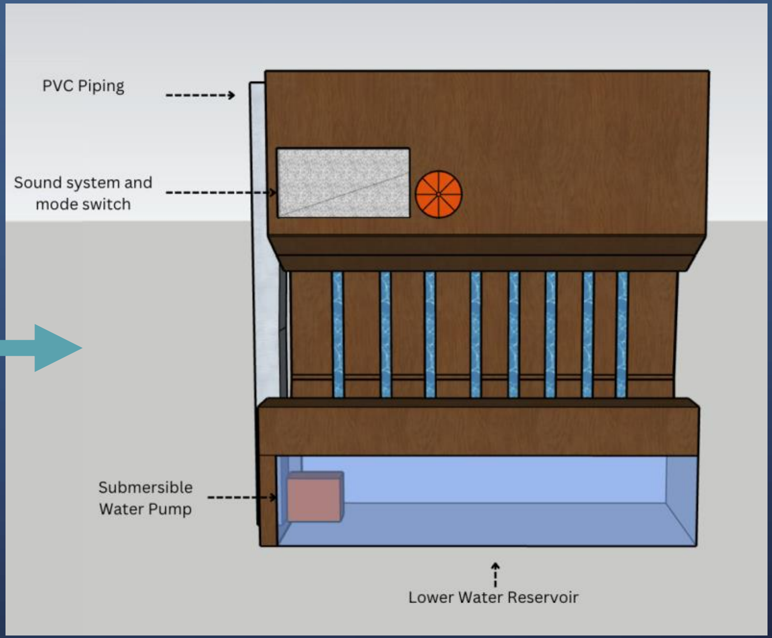
Table 2.5.1: *Engineering Specifications Table*

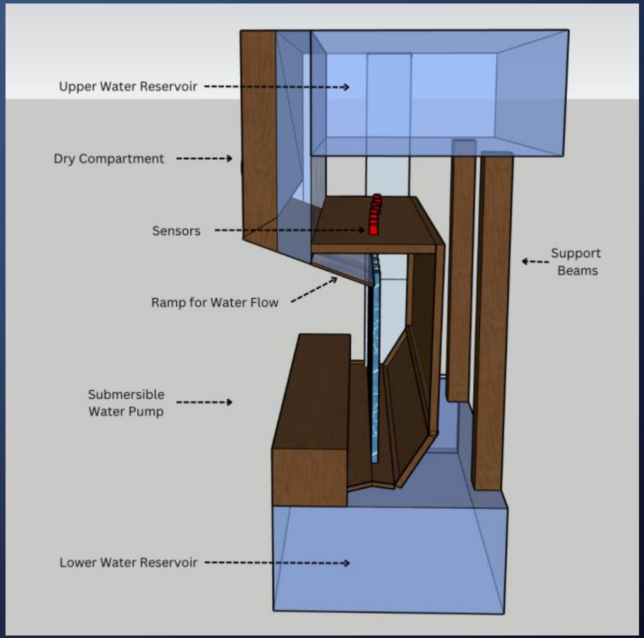
Component(s)	Parameter	Specifications
Photoresistor	Detection Time	< 10 ms
Photoresistor, MCU, Speaker	Response Time	< 100 ms
Water Pump, PVC	Water Level Maintenance	< 2 in of water in lower reservoir
Laser	Wavelength	650 nm (Red)
Laser	Power	< 5mW
Pump	Flow Rate	2.3 gallons / minute
Pump	Lift Height	< 1.5 m
Reservoirs (Upper/Lower)	Capacity	2 gallons each

HARDWARE TECHNOLOGY - WATERPROOFING



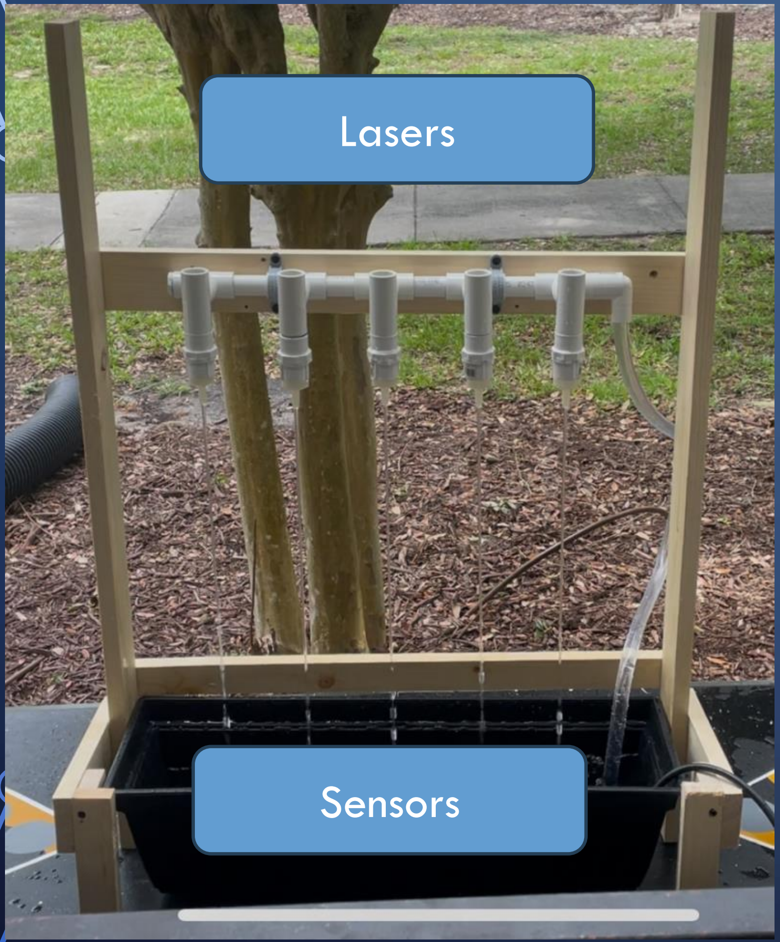
- Prototype Ver. 1





- Prototype Ver. 2

HARDWARE TECHNOLOGY - WATERPROOFING



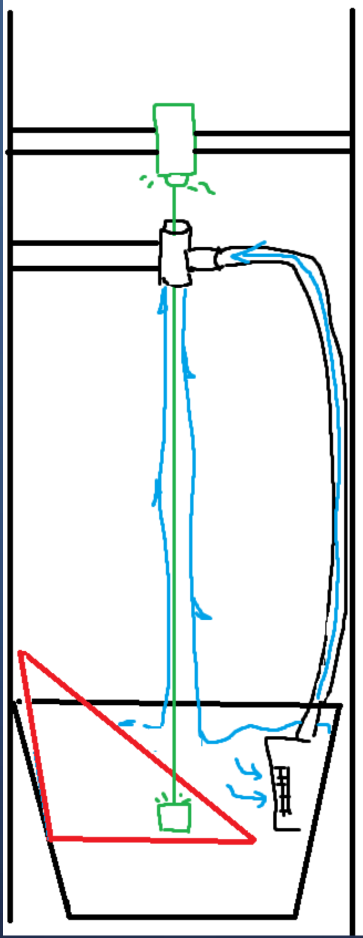


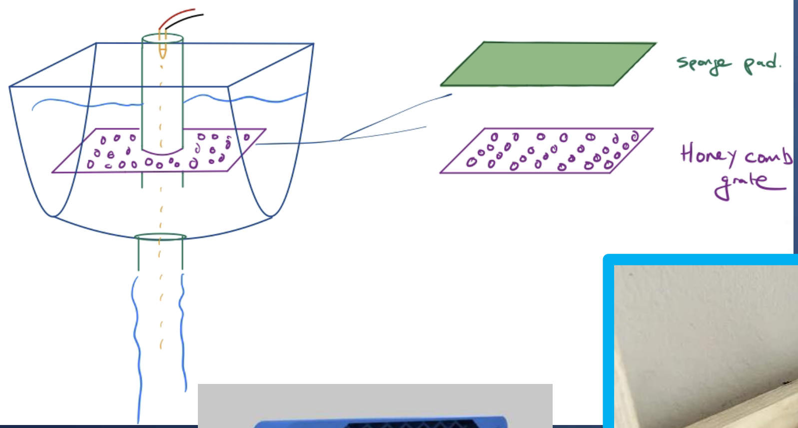
Table 3.1.6.4.1: *Waterproof Technology Comparison Table*

Feature	Mineral Oil	Waterproof Enclosure	Potting Electronics	Moisture Protection
Functionality	Submerge electronics in a non-conductive liquid to circumvent water damage	Seal electronics inside of an enclosure that allows them to function while submerged	Fully encapsulate electronics in resin for permanent waterproofing	Additional measure utilizing silica gel or coating to prevent moisture inside options 2 and 3
Advantages	No need for airtight sealing	Reusable and maintenance accessible, potentially compatible with laser	Offers most extreme waterproofing and durability	Good for additional layer of protection and synergizes with enclosure and potting
Disadvantages	Messy, difficult to clean, not suitable for user interaction	Requires proper sealing and cable gaskets	Inaccessible to maintenance, may block laser	Not enough on its own, needs to paired

- Prototype Ver. 3

HARDWARE TECHNOLOGY - LAMINAR FLOW

- To ensure proper, functional use of our detection system, we need precise alignment for the water strings.



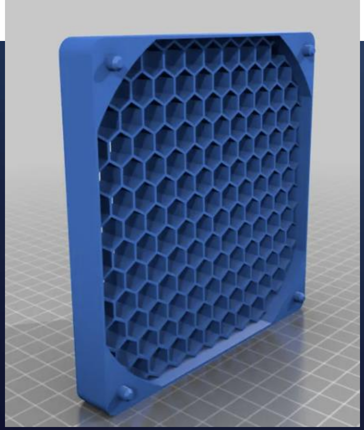
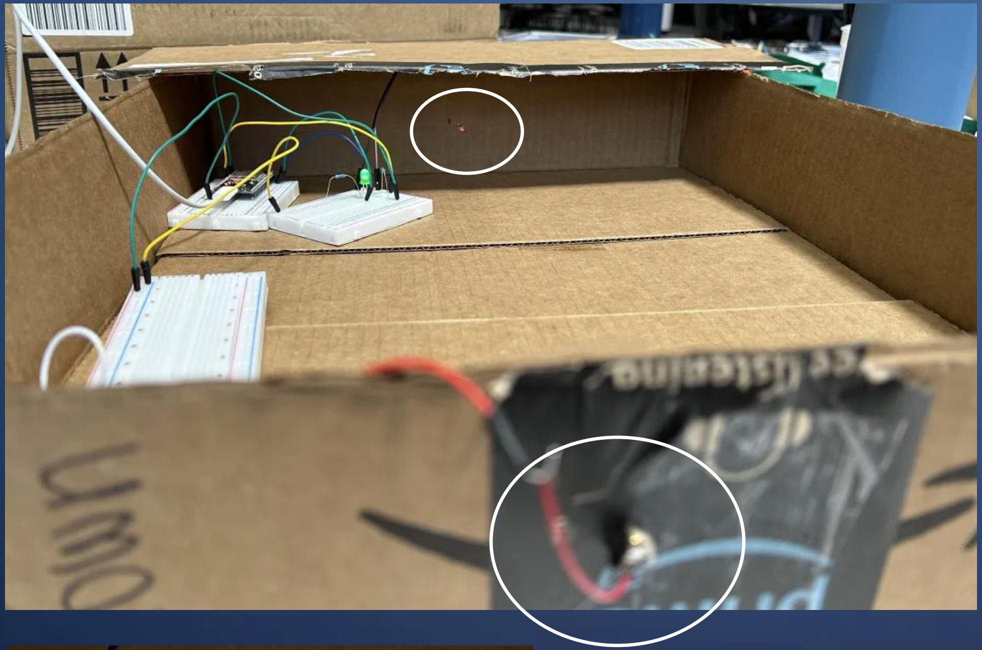


***Table 3.1.4.3.1:** Laminar Flow Specification Comparison*

Specification	Perforated Material	Honeycomb Flow Straighteners	Funnels	Pressurized Nozzles
Efficiency in Achieving Laminar Flow	Moderate (Reduces turbulence for low-velocity flow over high-velocity flow)	High (Structures are more uniform with parallel pathways)	Moderate (Best for directing flow but doesn't ensure laminar flow)	High (Maintains constant pressure forcing the water to flow in a non-turbulent path)
Design Complexity	Simple (can easily be constructed with a drill and spare plastic)	High (requires a uniform pattern, possible 3D print)	Simple (can obtain from store)	Simple (connect PVC piping together to control flow of water)
Cost	~$1 - $5	~$5 - $10	~$5 - $10	~$10

HARDWARE TECHNOLOGY - LASER SENSOR

- How to detect when the user's hand passing through a water string?



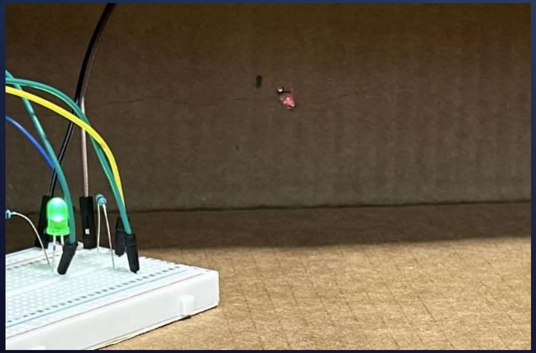


Table 3.1.3.5.1: *Sensor Comparison*

Specification	Capacitive Sensor	Ultra-sonic Sensor	Piezo-electric Sensor	IR Beam Sensor	Laser Beam Sensor
Detection Method	Changes in conductivity (capacitance)	Echo detection, pattern recognition	Mechanical stress conversion, pattern recognition	Transmitter-receiver beam interruption	
Possible False Triggers	High (humidity & temp interference)		High (vibration inter-ference)	Moderate (water absorption)	
Alignment Difficulty	Low (mounting two metal plates)	High (multiple sensors pointing at strings next to one another)	High (mounting issues, water strings are too close together)	High (beam is not visible to human eye)	Moderate (beam is visible)
Effective Range	Limited (effective within centimeters)	Mid-range (~1 to 2 feet)	Less than a few centimeters	~1.5 feet MAX	~6 feet MAX
Cost & Availability	$5 - $20	$10 - $20	$2 - $25	$3 - $25	$3 - $10

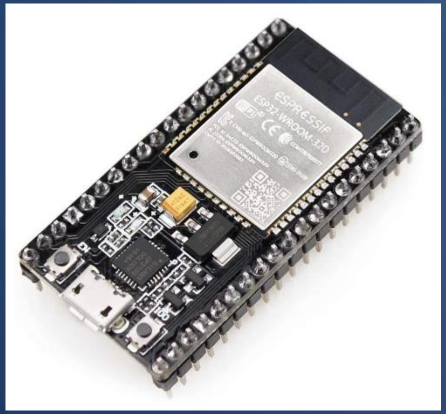
HARDWARE TECHNOLOGY - LASER BEAM

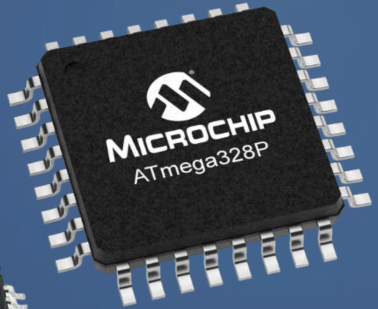
- All lasers generally feature same parameters/cost. Distinction lies in combability with sensor and style.
- Visible laser for aesthetics VS invisible laser for immersion

Table 3.1.6.4.1: *Laser Technology Comparison Table*

Feature	Diode Laser	Line Laser	Infrared Laser	VCSEL
Cost	\$5 - \$20	\$10 - \$50	\$10 - \$20	~\$20
Wavelength Range	400 – 980 nm (generally)	400 – 980 nm (generally)	780 – 1550 nm	400 – 940 nm
Power Output	1 – 5mW	1 – 5mW	1 – 100mW	0.1 – 10mW
Beam Shape	Circular Dot (on surface)	Thin line	Circular Dot	Circular Dot
Functionality	Emits a focused beam on the aimed surface	Projects a thin, visible line to emulate a string	Invisible laser detection for more subtle applications	Similar to Diode, utilizes a more efficient technology
Advantages	Cheapest, easy to integrate, has many colors	Visible laser allows for aesthetic applications	No visible beam allows for seamless applications	High-speed and very efficient, lowest power output
Disadvantages	More susceptible to divergence	Reflections from water can refract the beam itself	Needs appropriate IR-sensors	Higher cost than diode, less accessible

HARDWARE COMPONENT - MICROCONTROLLER





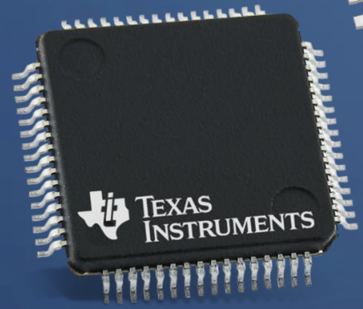


***Table 3.2.1.6.1:** Comparing Microcontrollers*

Feature	ATmega 328 (Uno)	ATmega 2560 (Mega)	MSP430 FR6869	ESP32	Teensy 4.0
Cost	20.00 (Mouser)	48.40 (Mouser)	24.00 (DigiKey)	8.00 (Mouser)	23.80 (Adafruit)
Size (board)	68.6 x 53.4 mm	101.52 x 53.3 mm	89 x 58 mm	51 x 25.5 mm	35.56 x 17.78 mm
Manufacturer	Microchip	Microchip	Texas Instruments	Espressif Systems	PJRC
ADC Resolution	10-bit 8 inputs	10-bit 16 inputs	12-bit 16 inputs	12-bit 18 inputs	2 x 12-bit 10 inputs
PWM Channels	6	15	8	16	31
Number of GPIO Pins	23	86	83	34	40
Communi-cation Interfaces	1 x UART 1 x I2C 1 x SPI	4 x UART 1 x I2C 1 x SPI	2 x UART 2 x I2C 2 x SPI	3 x UART 2 x I2C 4 x SPI	3 x UART 3 x I2C 3 x SPI
Power Consumption, Active Mode (per 1 MHz)	200uA	500uA	100uA	~200mA	100mA
Best Feature	Simple, low power	Many I/O and PWM	Ultra-low power, DAC	High memory, DAC	Fastest, USB MIDI

***Table 3.2.1.5.4.1:** Comparing Microcontroller Audio Systems*

Feature	ATmega (Both models)	MSP430	ESP32	Teensy 4.0
DAC (native)	No	Some models (FR6869)	Yes	Yes
PWM sound	Yes	Yes	Yes	Yes
External DAC needed?	Yes	Maybe	No	No
MIDI support	No (requires module)	No (requires module)	Yes (USB or Bluetooth)	Yes (native USB-MIDI)

HARDWARE COMPONENT - SPEAKER

- Speaker choice needs to balance power consumption and audio quality + volume
- Louder = More Power

Table 3.2.3.5: *Comparison of Speakers*

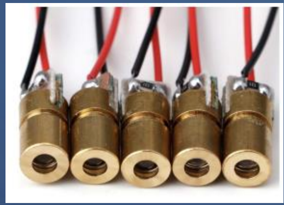
Feature	Passive Speaker	Active Speaker	Exciter Speaker	Piezo Speaker	Hi-Fi Speaker
Cost (general)	~ $3 - $8	~ $10 - $20	~$3 - $20	$0.5 - $3	$30 - $100
Sound Quality	Good	Good - Excellent	Surface-dependent	Poor - Good	Excellent
Size	Small - Medium	Medium - Large	Small	Very Small	Very Large
Complexity to Integrate	Moderate (need amplifier)	Moderate (need 3.5mm or Bluetooth)	Moderate (surface/ frame dependent)	Very Low (near plug and play)	High (need amplifier/ external power)
Power Consumption	Moderate (3 – 10W)	High (10 – 30W)	Moderate (1 – 10W)	Very Low (0.1 – 1W)	Very High (20 – 100W)
ESP32 Compatibility	Yes (with amplifier + module)	Yes (with amplifier + module/BT)	Yes (with amplifier)	Yes (PWM output)	Yes (with DAC + amplifier)

HARDWARE COMPONENT - LASER

Laser 3.2.4.1.1
GH05210H2K (GREEN)

Laser 3.2.4.1.4
B07M9DTSF7 (BLUE)

Laser 3.2.4.1.2
GM532-50B (GREEN)



Laser 3.2.4.1.5
B088PQQ9XV (RED)

Laser 3.2.4.1.3
B0CYL53LVG (BLUE)

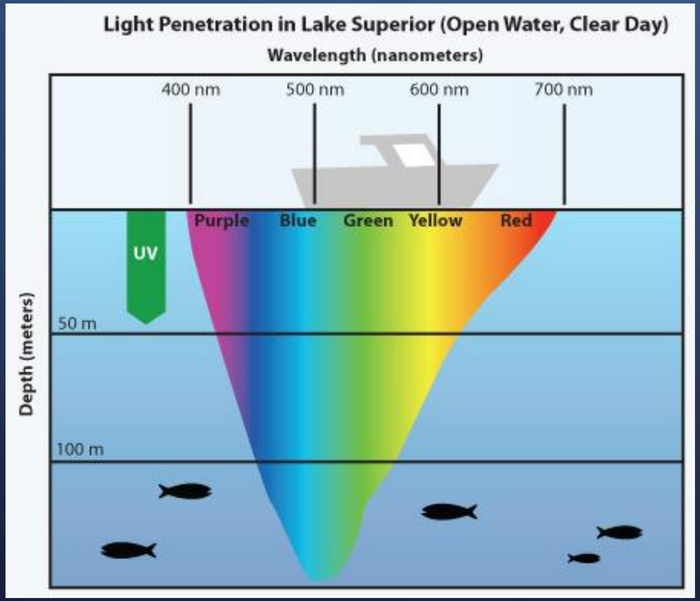


Table 3.2.4.1.5.1: Laser Comparison

Specification	Laser 3.2.4.1.1	Laser 3.2.4.1.2	Laser 3.2.4.1.3	Laser 3.2.4.1.4	Laser 3.2.4.1.5
Color (Wavelength)	Green (520nm)	Green (532nm)	Blue (405nm)	Blue (405nm)	Red (650nm)
Power Output	15 mW	5 mW	5 mW	20 mW	5 mW
Voltage	5.8 V	3 - 3.7 V	3 – 5 V	3 – 5 V	2.8 - 5.2 V
Current	35 mA	200 mA	–	< 120mA	25 mA
Laser Type	Dot	Dot	Line, Cross, Dot	Dot	Dot
Dimensions	–	1.3" L x 1.3" W	12mm x 30mm	14mm x 45mm	10 mm x 31 mm
Operating Temperature	-10°C to 60°C	0°C to 50°C	15°C to 35°C	10°C to 40°C	-10°C to 40°C
Cost	$8.00 + shipping	$10.00	$8.00	$11.99	$6.99 + shipping (for 20 pcs)

- Absorbtion of laser beams into water

HARDWARE COMPONENT - SENSOR

Photodiode 3.2.4.2.1
475-BPW34-ND

Photodiode 3.2.4.2.2
475-SFH213-ND

Photodiode 3.2.4.2.3
751-1013-ND

Photodiode 3.2.4.2.4
B07VNSX74J

Table 3.2.4.2.4.1: *Photodiode Comparison*

Specification	Photodiode 3.2.4.2.1	Photodiode 3.2.4.2.2	Photodiode 3.2.4.2.3	Photodiode 3.2.4.2.4
Wavelength Range	430nm – 1100nm	400 nm – 1100 nm	420 nm – 675 nm	400 nm – 1100 nm
Peak Wavelength	850 nm	850 nm	565 nm	940 nm
Current	Dark, 2nA	Dark, 1nA	Dark, 2nA	--
Viewing Angle	120°	20°	100°	40°
Dimensions	5.4 mm	37 mm x 5.9 mm	--	26 mm x 0.5 mm
Temperature	-40°C to 85°C	-40°C to 100°C	-40°C to 125°C	-40°C to 100°C
Response Time	20ns	5 ns	--	--
Active Area	7 mm^2	1 mm^2	--	--
Cost	$1.14 + shipping	$0.85 + shipping	$11.38 + shipping	$7.29 ($0.36 pu)

- Supply chain issues

HARDWARE COMPONENT - WATER PUMP

"Smartpond" Submersible Fountain Pump

DiversiTech Thermoplastic Condensate Pump

Key Features:

- 155 GPH (2.5 GPM) capacity
- Variable speed dial for a dynamic flow rate (ideal for calibration)
- Flow rate satisfies minimum requirements for necessary gallons per minute
- Emergency shutoff sensor if water level gets too low
- No sound

Comparison of Water Pumps

Specification	Submersible Water Pump	Condensate Water Pump
Voltage	120V	120V
Horsepower	0.0094 hp	0.033hp
Length	3.05in	8.1in
Width	4.68in	3.42in
Height	6.8in	5in
Cost	$33.98	$99.98
Low Water Shut Off	Yes	Yes
Flow Rate Ajustibility	Yes	No
Gallons Per Hour	155 GPH	96 GPH
Vertical Lift	42.5 in.	240 in.

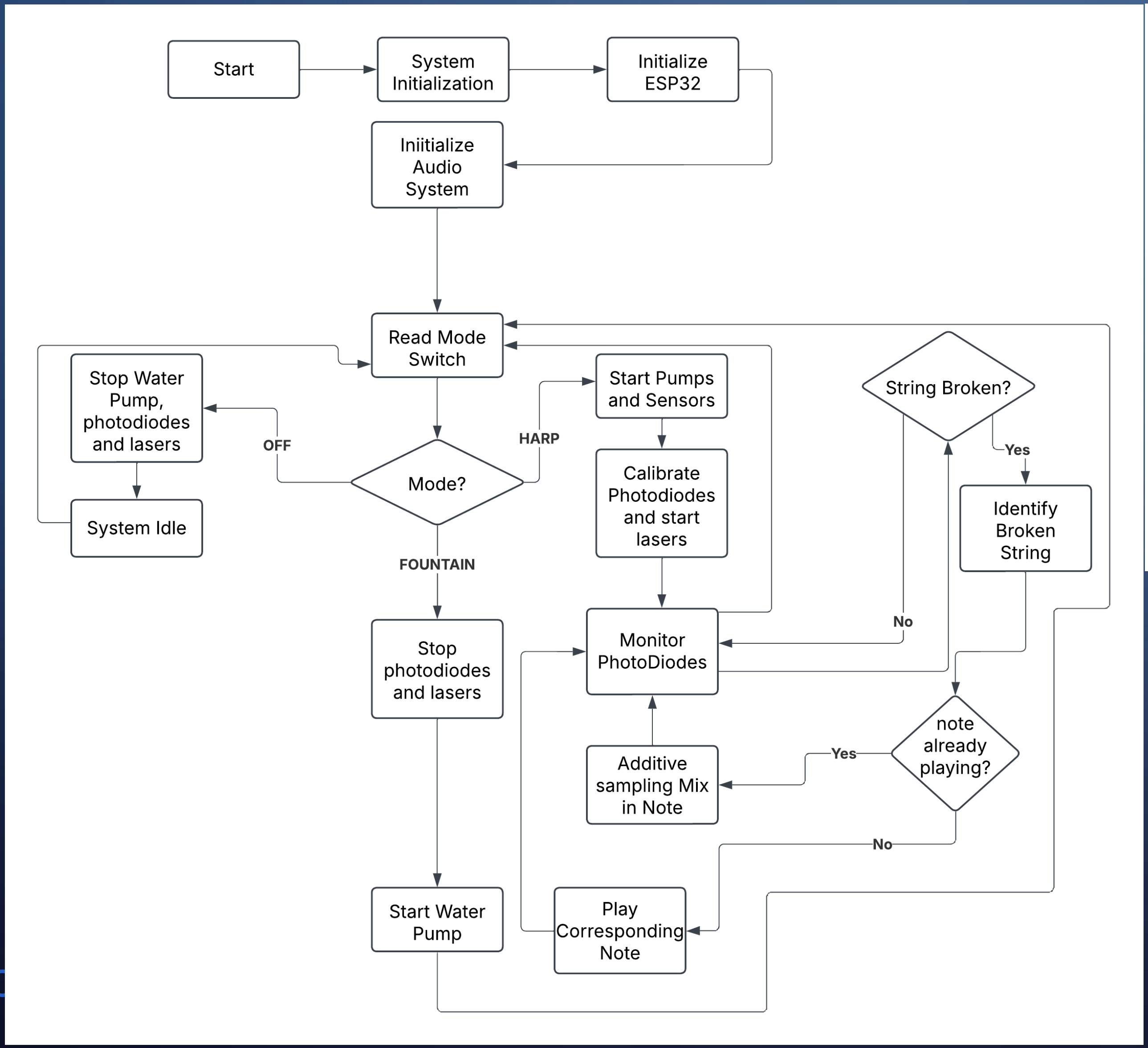
SOFTWARE DESIGN – PROGRAMMING LANGUAGE

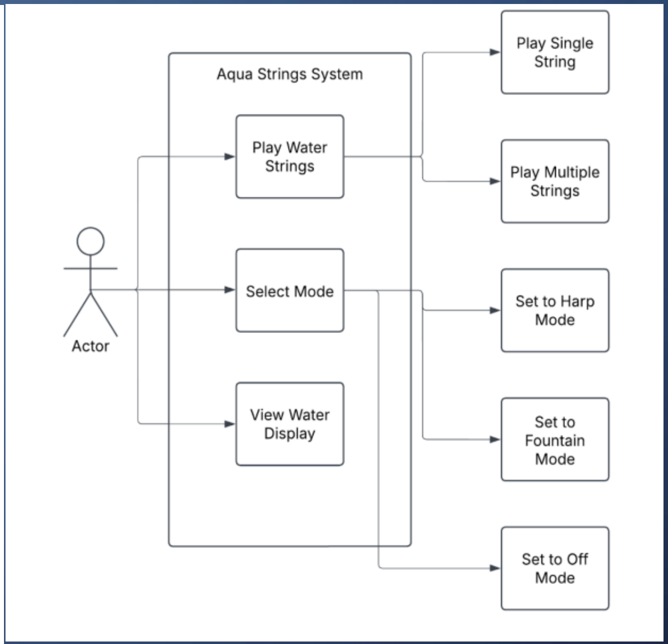
Language	Dev Difficulty	Power Eff.	Exec Speed	Libraries	Docs Available	Learn Curve
C++	Medium	Great	Great	Excellent	Excellent	Moderate
Micro Python	Low	Poor	Fair	Good	Good	Easy
JavaScript	Medium	Poor	Poor	Fair	Fair	Medium
Rust	High	Great	Great	Good	Good	Hard

Biggest factors:

- **Performance:** performance is critical for making full use of the esp32 and avoid delays
- **Ecosystem:** good library support for audio on the esp32 using the ArduinoIDE

SOFTWARE DESIGN - MAIN PROGRAM

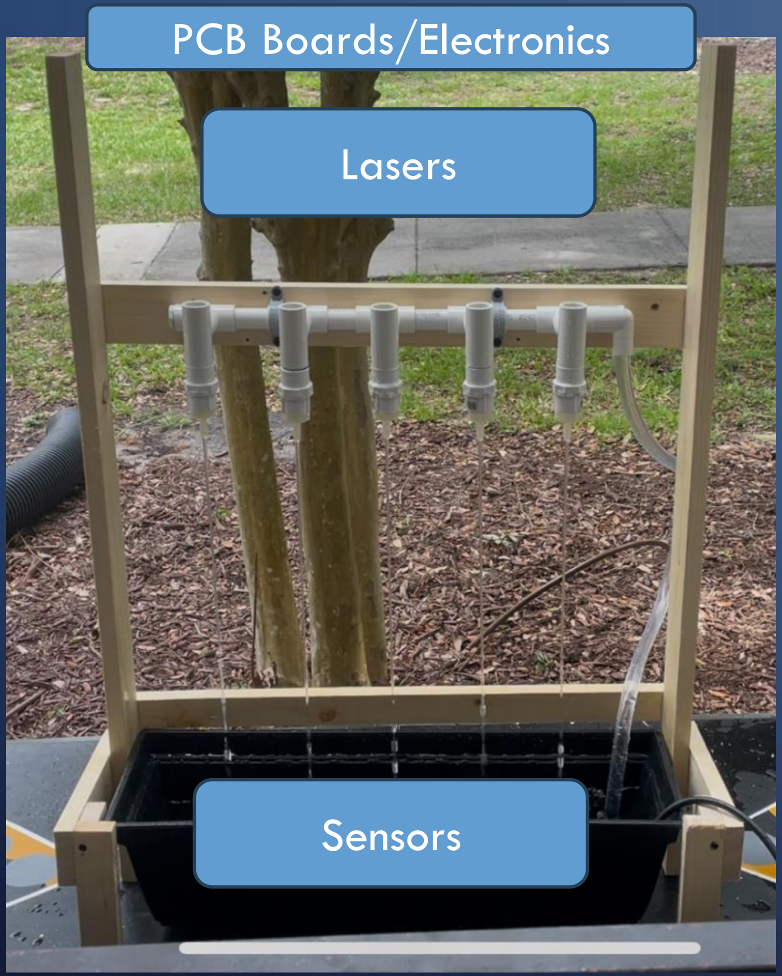


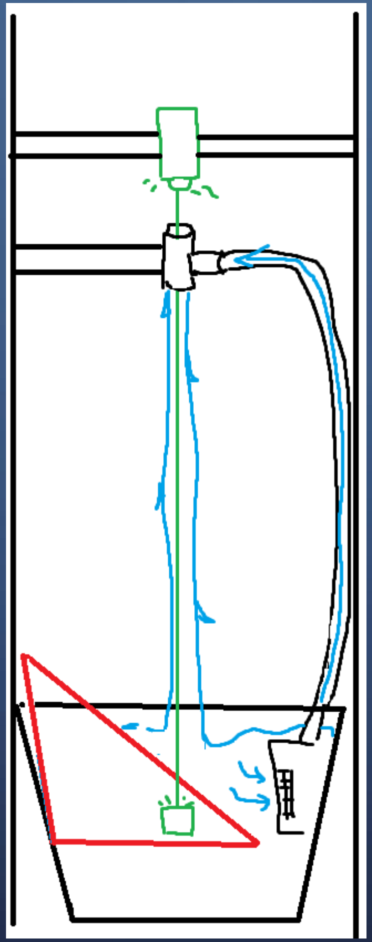


Libraries used:

- Arduino.h: standard ESP32 Functions
- SPI.h: Communication with SD card
- SD.h: reading and writing to SD card
- arduino-audio-tools.h: Audio Decoding, and mixing

HARDWARE DESIGN

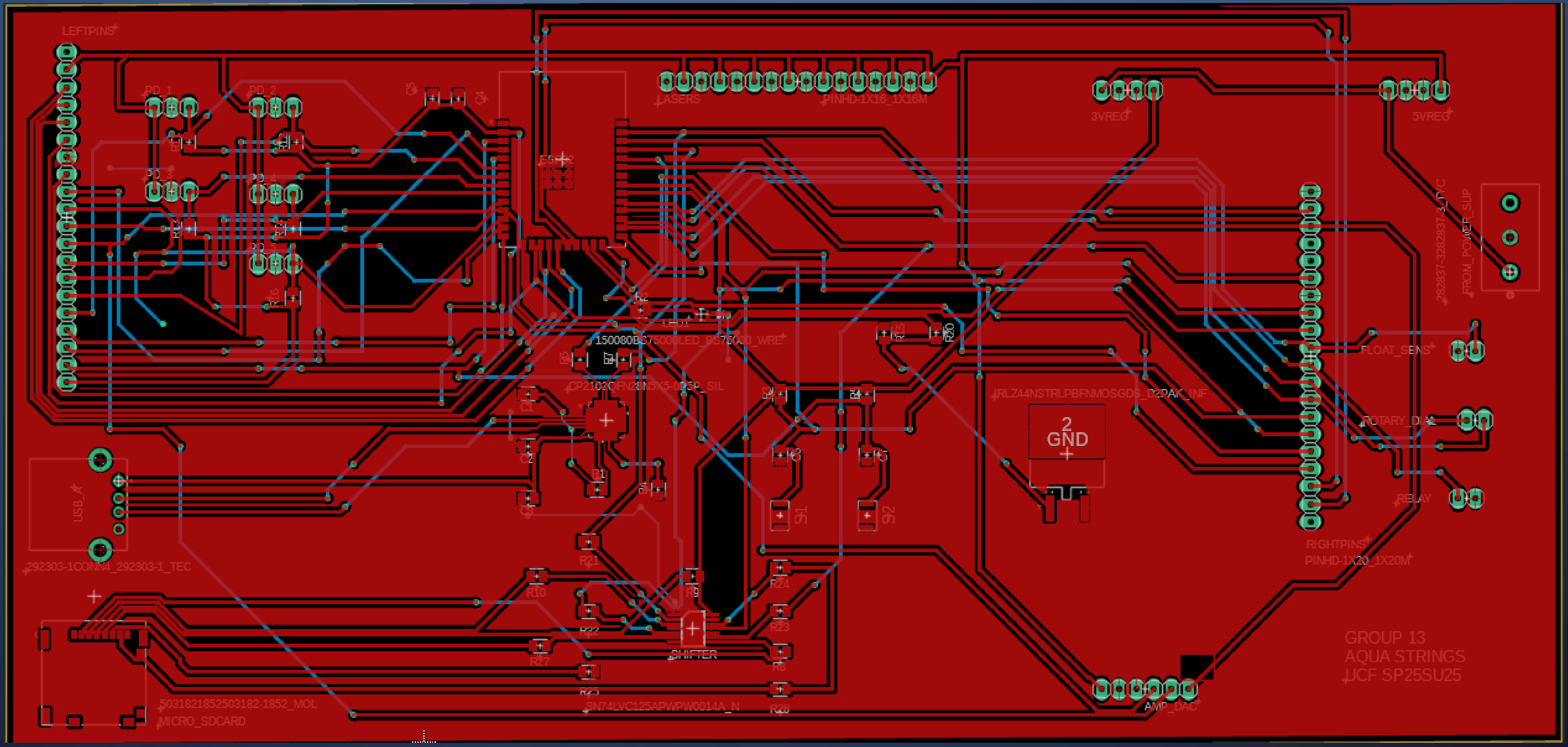




Current design:

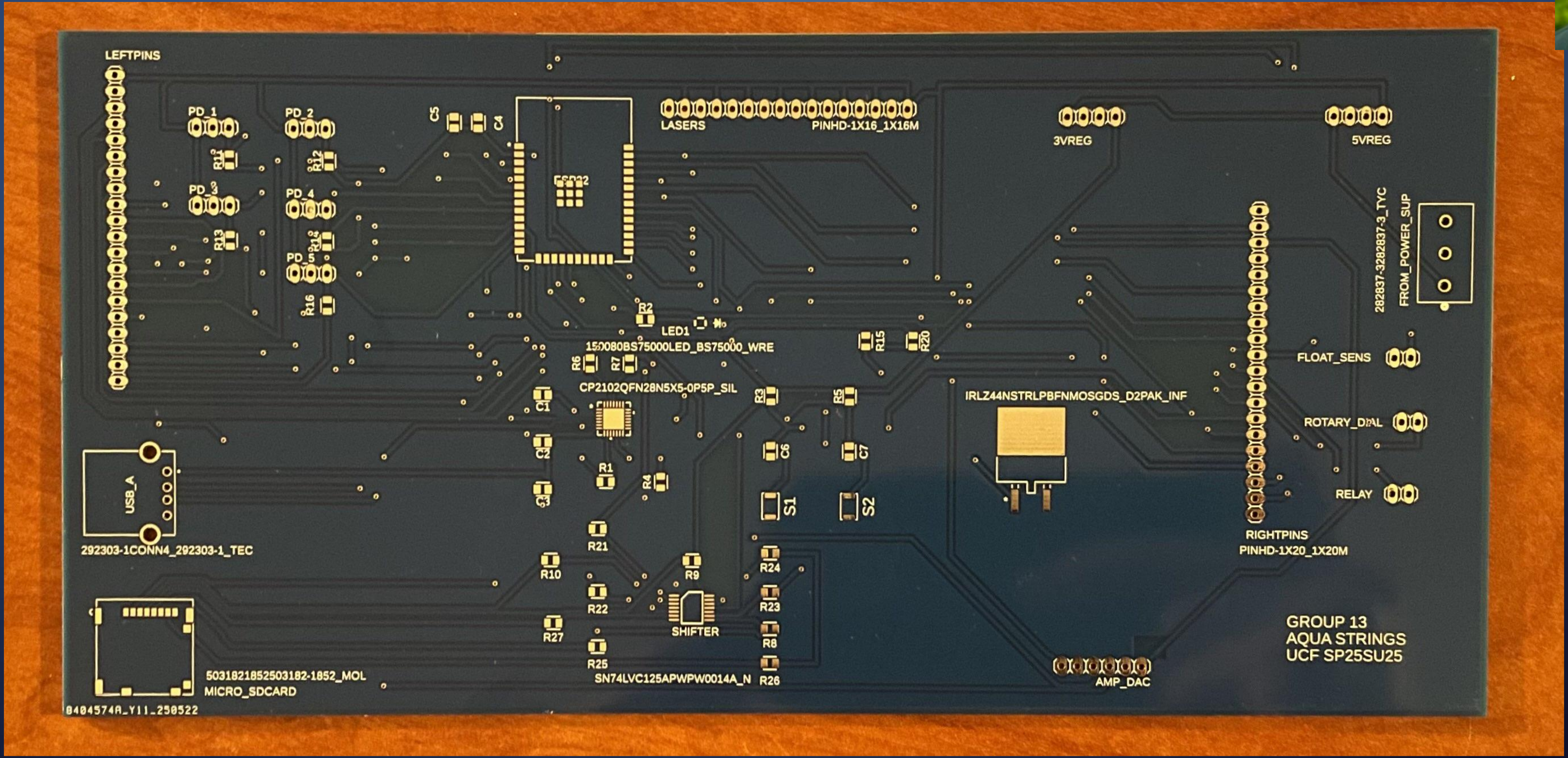
- Water flow
    - Movement counterclockwise
- Top Shelf
    - PCB and all other electronics located in dry zone
    - Lasers pointing down from the top of PVC spouts
- Bottom Ramp
    - Reduces water noise
    - Plexiglass angled away from user for eye safety

PCB DESIGN



- Main Microcontroller PCB

PCB DESIGN



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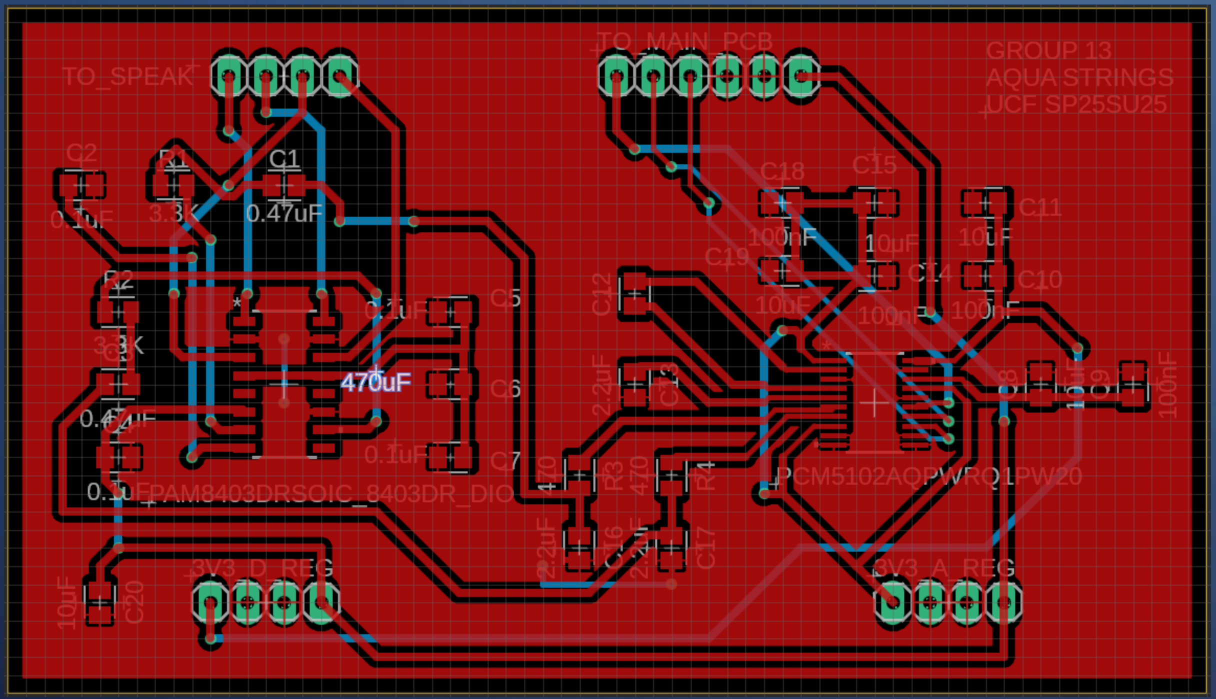
PCB DESIGN

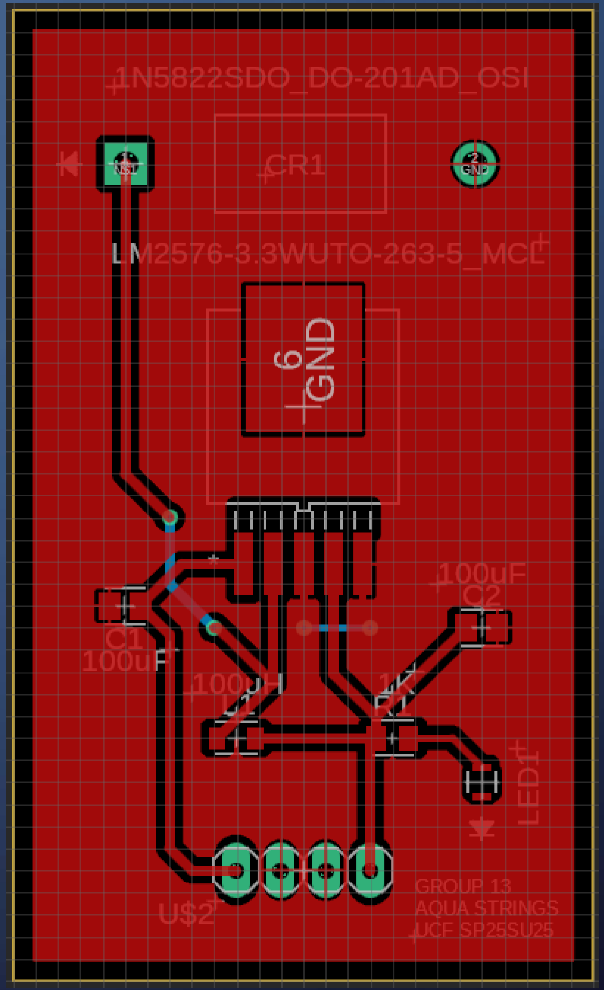


Audio Amplifier & DAC Board

(PAM8403 and PCM5102)

ESP32 (8-bit @ 44kHz sample rate vs.

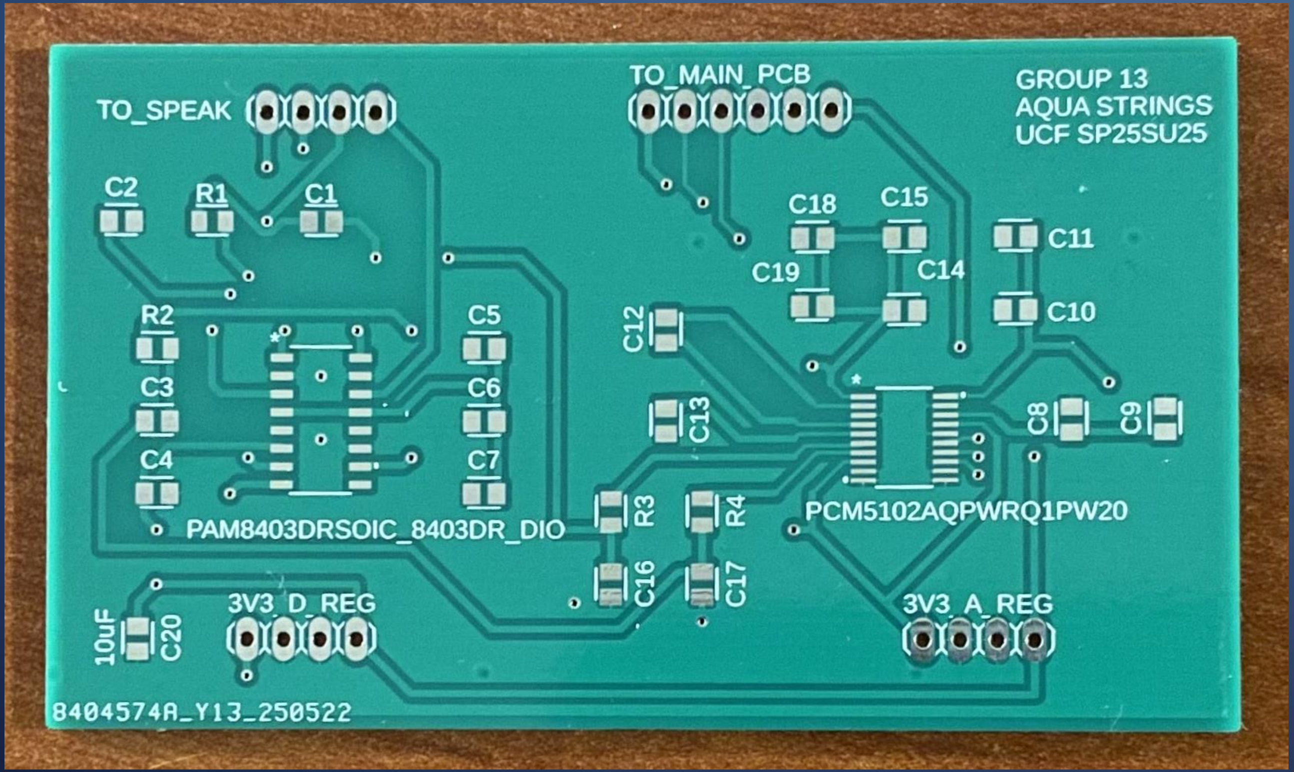
PAM8403 (32-bit @ 384kHz sample rate)



3.3/5V Voltage Regulator

(LM2576 – 3.3/5.0)

PCB DESIGN



Audio Amplifier & DAC Board

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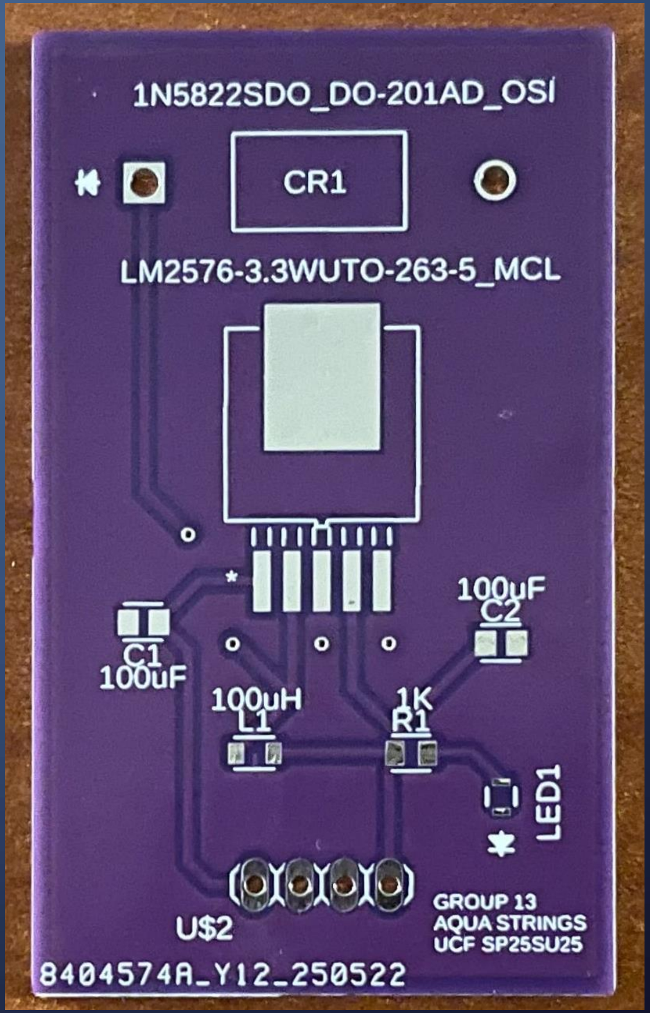
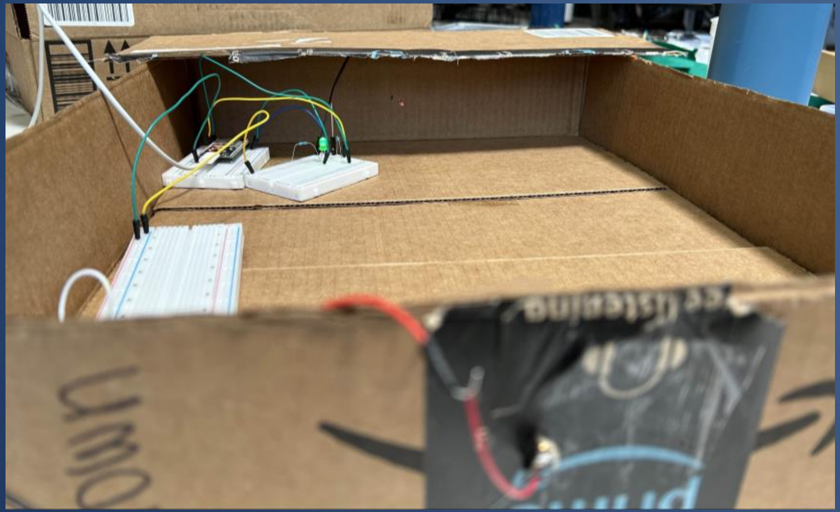
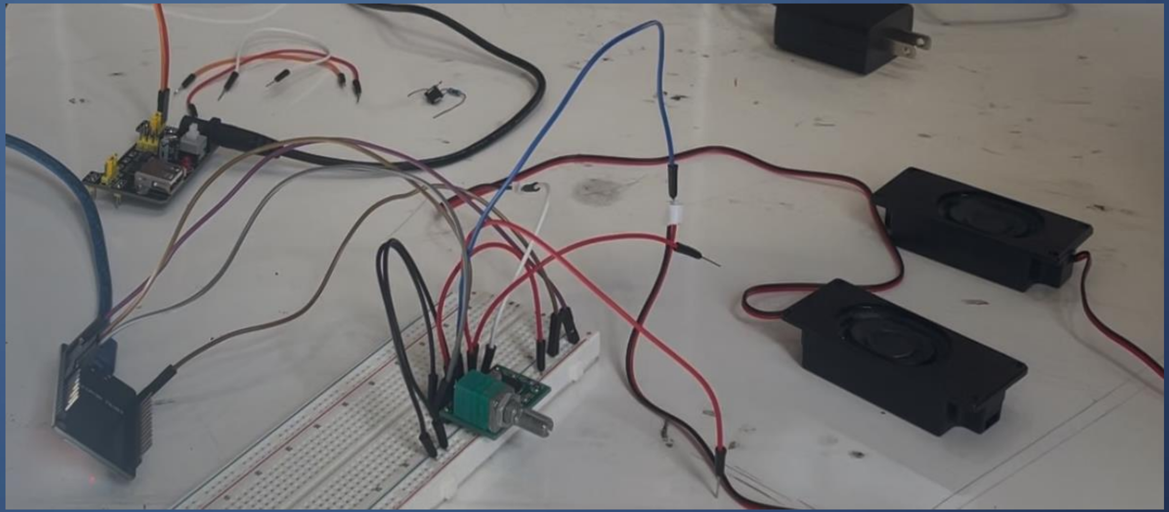


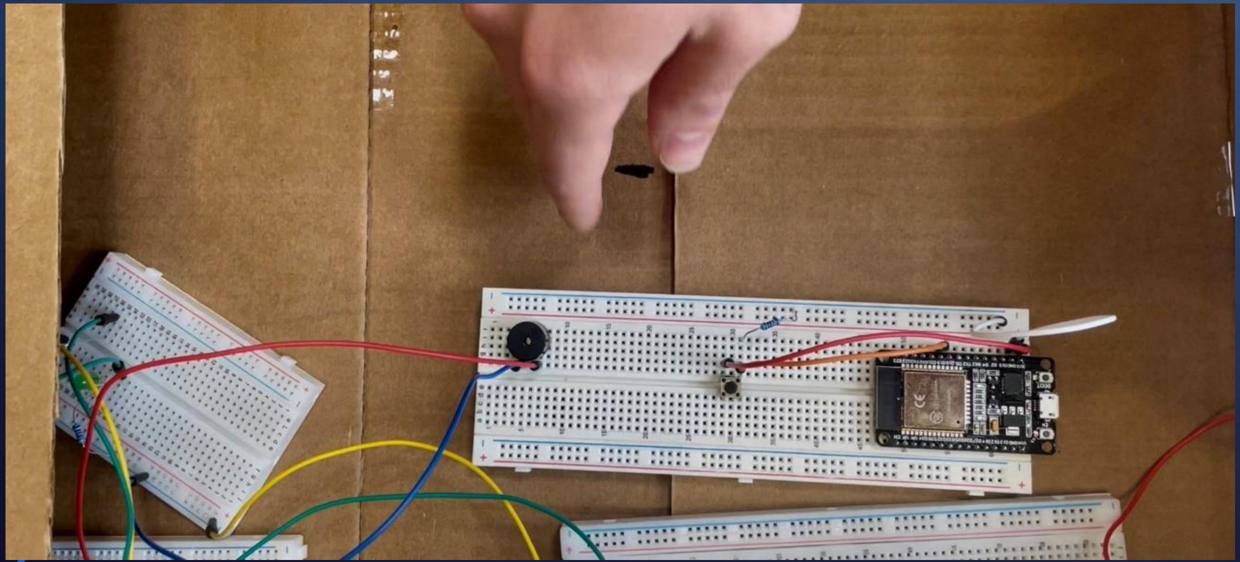
3.3/5V Voltage Regulator

(LM2576 – 3.3/5.0)

PROTOTYPING AND TESTING







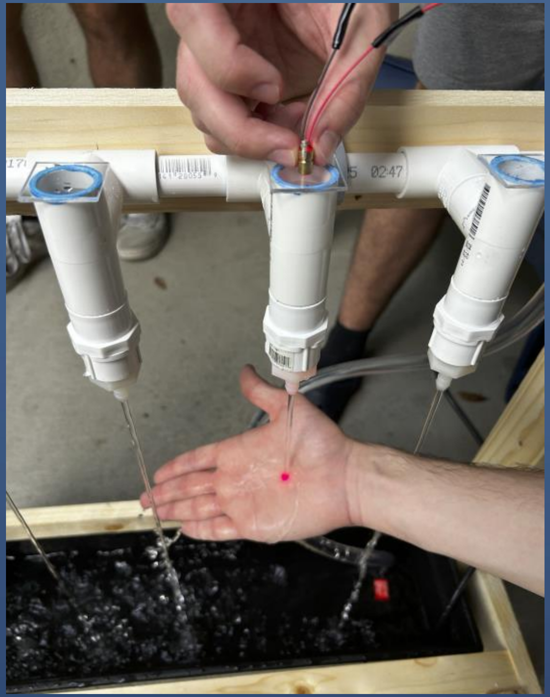
Successful testing for laser and photodiode compatibility

- Ambient light offset for more accurate hand detection
- Buzzer output noise with little to no delay

- Speaker output
  - Communication with SD card
  - Subject to change

Next step: Laser integration with speaker

PROTOTYPING AND TESTING



- Wooden and waterproofed base frame
- Clear vinyl hose from pump to PVC
- ½in. PVC piping with 90° and tee connections
- ¼ in. barb fittings for water strings
- Clear plexiglass for mounting lasers

Areas of improvement:

1) How to mount on lasers
2) Laminar flow relationship

ADMINISTRATIVE CONTENT (BUDGET)

Part	Final Price ($)	Subsystem
Water Pump	$36.19	Water System
Red Laser Diode (x20)	$9.55	Detection
Audio Amplifier (x2)	$10.06	Audio
Photodiode (x5)	$7.02	Detection
Speaker (x2)	$8.55	Audio
Power Supply	$16.39	Electronics
Relay	$11.76	Electronics
Rotary Dial	$12.45	User Control
Fuses	$12.93	Electronics
Micro SD Card Reader Module	$6.99	Electronics
PCBs (JLCPCB)	$95.58	Electronics
Wire AWG 18	$8.39	Electronics
Laser clips for mounting	$6.38	Detection
Waterproof Spray, Screws, Acrylic sheet	$22.92	Structure
DAC	$11.99	Audio
PVC Pipes + Lower Reservoir (2 purchases)	$49.71	Water System
Vinyl Tube (for water pump)	$12.64	Water System
Plexiglass, pvc adapters and reducers	$19.40	Structure
Wood, clamps, screws, and new reducers	$46.16	Structure
Last reducer and adapter	$5.45	Structure
PCB Components	$153.47	Electronics
Total	$563.98	

WORK DISTRIBUTION

***Table 10.3.1:** Work Distribution Layout*

Electrical Engineering	Project Responsibilities
Christopher Brown	Chapter 1: Executive Summary Chapter 3: Sensor Selections / Laminar water Flow Chapter 6: Hardware Design Chapter 8: PCB Design Laser Detection Mini Demo Video

Computer Engineering	Project Responsibilities
Ryan Bori	Chapter 5: Comparison to AI Chapter 7: Software Design Chapter 10: Administrative Content Report Citations Speaker Output Mini Demo Video

Electrical Engineering	Project Responsibilities
Trenton Morris	Chapter 3: MCU/Speaker Selection Chapter 3: Audio Output Chapter 8: PCB Chapter 9: System Testing Power Supply Documentation Component Overview Mini Demo Video Speaker Output Mini Demo Video

Electrical Engineering	Project Responsibilities
Mikaella Penagos	Chapter 2: Prototype Illustrations Chapter 3: Water Pump Selection Chapter 4: Project Standards and Constraints Chapter 10: Administrative Content Chapter 11: Conclusion Water Pump Mini Demo Video

PLAN FOR COMPLETION

Week #	Task
Week 4	• Develop CDR Presentation Material and Recordings • Order PCB and Components to solder
Week 5	• CDR Presentation and Live QnA Session (6/13 @ 1:00) • Begin soldering PCB
Week 6-7	• Continue work on frame and mount electronics • Finalize soldering PCB • Produce an operating type for demo presentation
Week 8	• Midterm Demo Meeting (6/30 @ 3:30)
Week 9-10	• Secure components to frame • Test for laser detection and refine accuracy • Test for audio quality/volume and refine output
Week 11	• Live Demo and Final Review Showcase (7/22 -7/24)
Week 12	• Final Documentation and Videos (7/29 @ 12:00) • Individual Peer Review Report, Exit and Junior Design Survey (7/29 @ 12:00)