Ultrasonic Object Detector

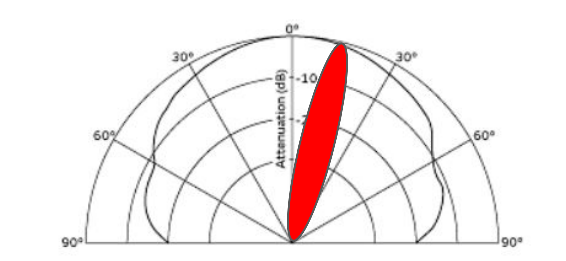
sdmay25-36

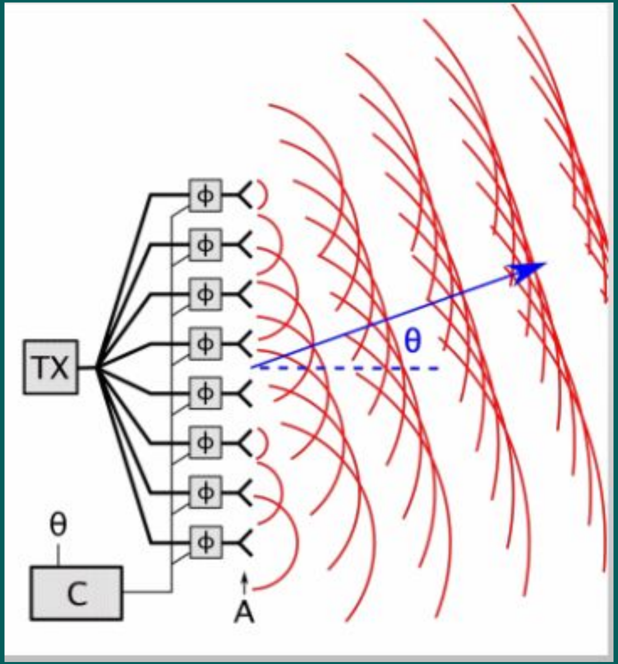
- Brock Dykhuis
- Nate Clarke
- Nicholas Jacobs
- Jonathon Madden

Phased Arrays Basics

- Utilizes constructive and destructive interference to steer and focus a beam or pulse.

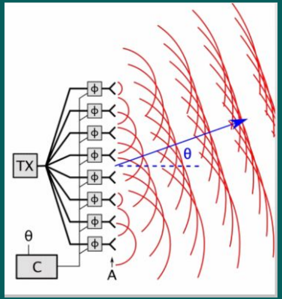
- Each transmitter has its own attenuation (signal area)
    - Taking advantage of well calculated time delay we can enhance the signal in the intended direction, and cancel out unneeded signals outside of the intended scanning range.





Project Overview

- Design an object detector ultrasonic pulses



- Use a phased array of transducers
- Rely on reflected sound waves to determine object distance
- Use of time-delay (phase) to control scanning direction and location

Problem Statement

- Design an ultrasonic phased array system which can detect small objects
- Accurately detect two or more objects in close proximity
- Effectively convey a detection image through the use of an intuitive display

Functionality

- Some example uses in practice include:
  - Medical diagnostics
  - Non-destructive testing
  - Underwater navigation
- In our case the radar will detect small objects, and it is not designed for outdoor use.
- The radar will be able to detect two or more separate objects in close proximity
- The radar will be accurate up to a range of 1 meter.

New Ideas

- Raspberry Pi
  - Send radar data wirelessly through a raspberry pi

- Make improvements on the display, so objects can be clearly seen
  - Outlining, labeling, or color coding potential objects by collecting points in close proximity
  - Improving the precision (down to mm)
- Changes to phased array layout:
  - Additional receivers

Pro/Con Table

Multi Receiver VS. Single Receiver System

Pros	Cons
• Increased accuracy (can combine data) • Increased effective range (combined FOV of multiple receivers)	• More expensive (requiring more receivers) • Increased components may increase risk of damage • Higher complexity for necessary calculations (particularly for phase delay)

Constraints

- Low cost for components
- Objects in close proximity should be clearly distinguishable
    - aiming for 2 cm tolerance
- Clear documentation
- Detect objects at least 1 meter away
- 10 transmitters and at least 1 receiver transducer in a phased array

Requirements

Functional

- Detect objects up to 1 meter away
- Display sweep for detected objects
- Using a phase array with phase delay to determine direction
- Use time delay to determine object distance
- Use 40 kHz ultrasonic pulses

Resource

- Server/Raspberry Pi for wireless data transmission
- External power source for powering the radar
- MA40S4S/R (10S, 1R)

Physical

- 10 transmitter/sender transducers in linear layout
- At least 1 transducer as a receiver
- Transmitters diameter is as small as possible (10 mm in diameter)

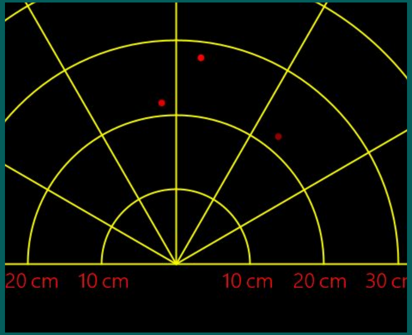
Requirements

Experimental

- Circuit simulator
  - Falstad/LTSpice
- Schematic Designs
  - Plan layout of circuit
- Oscilloscope
  - Test frequency range, components, etc.

Aesthetic

- Clear and readable display
- Clear object groupings



Environmental

- 40 kHz
  - Outside range of human hearing
- High sound intensity (120 dB) must be managed by undervolting transmitters

User Needs

Client Persona

Professor Song

- Ultrasonic radar system to detect objects
- Improve on past implementations of the project

Designers Persona

Our Group

- Design an ultrasonic radar
- Learn how sound waves are used to detect objects
- Learn what software and hardware are involved

Purchaser

Theoretical

- Easy to understand and interactive display
- A product that is easy to understand and setup
- Software that is adaptable to various devices (easy to deploy)
- Clear product documentation

Engineering Standards

IPC 2221

- This standard establishes design requirements for PCBs.
- This standard applies to the construction of the radar hardware, since it will be using a PCB board as its foundation.

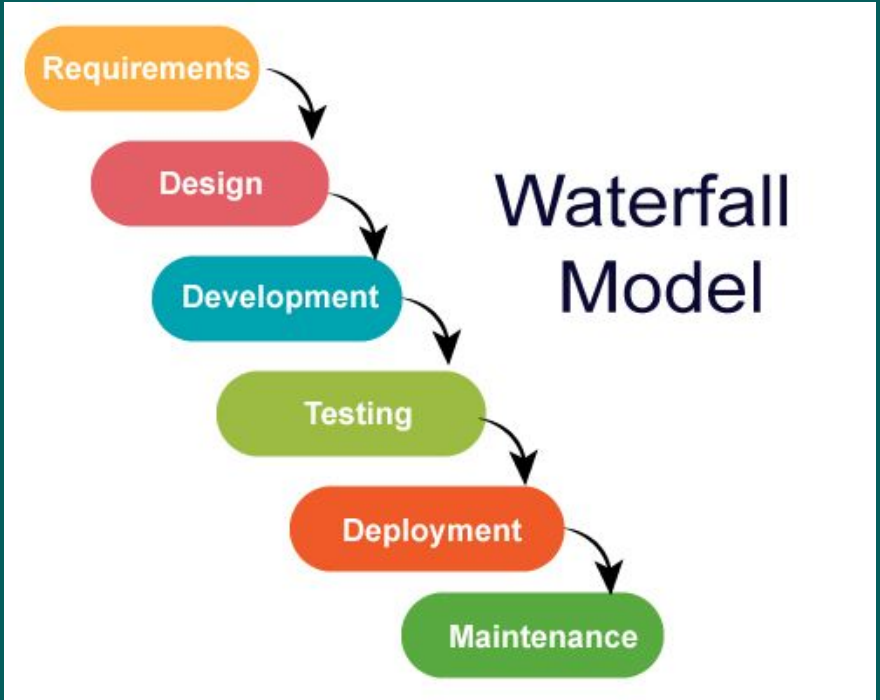
IEEE 1471-2000

- This standard deals with creating, analyzing, and maintaining software architecture
- Applies due to changing nature of radar display

IEEE 802.11

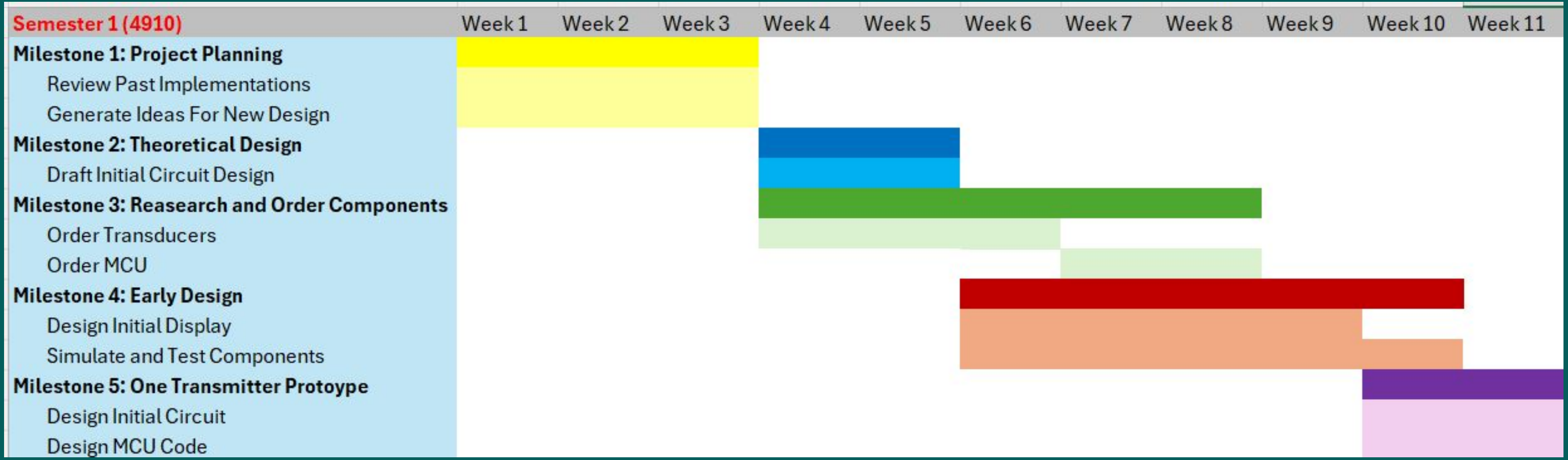
- This standard is about transmitting data to a computer wirelessly
- Will be using Raspberry Pi to communicate wirelessly

Project Management Style



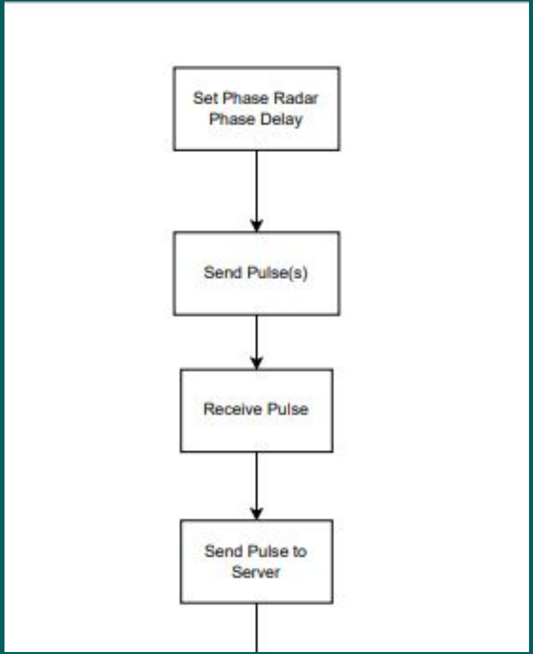
- Our project requires initial planning for what components to order.
- After determining component specifications we need to draft a design.
- Initial implementation will be creating the hardware design, followed by the display software design.
- We will then test the system and deploy an initial version.
- We will continue to maintain the system, improving its accuracy

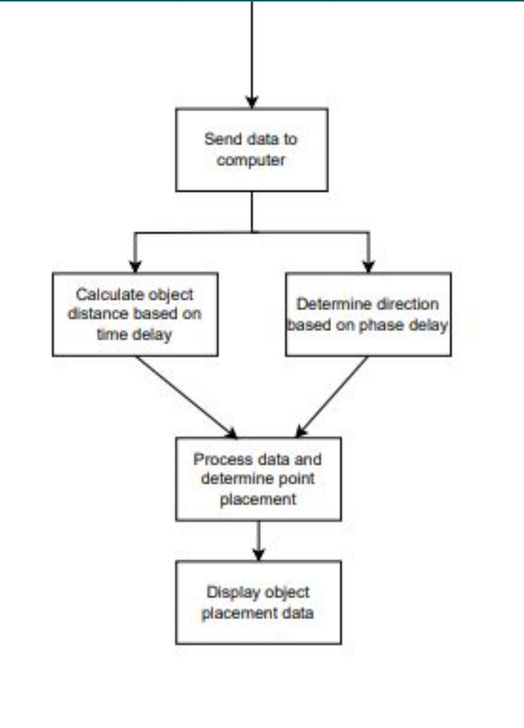
Gantt Chart



Semester 1 (4910)
Week 1
Week 2
Week 3
Week 4
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Week 11
Milestone 1: Project Planning
Review Past Implementations
Generate Ideas For New Design
Milestone 2: Theoretical Design
Draft Initial Circuit Design
Milestone 3: Reasearch and Order Components
Order Transducers
Order MCU
Milestone 4: Early Design
Design Initial Display
Simulate and Test Components
Milestone 5: One Transmitter Protoype
Design Initial Circuit
Design MCU Code

Task Decomposition





- The first major step is to set the array to a particular phase delay to determine the direction.
- After this the pulses are sent and received, and data is sent to the server.
- The data is then sent to the computer to process
- The data is processed to determine distance and direction
- Processed data is displayed on radar sweep.

Key Risks and Mitigation Strategies

Components

- Be careful with our transmitters and receivers, to make sure we do not fry too many of them
- Research components to ensure they have the right specifications needed for this project

On Task

- We meet weekly with our team and advisor to make sure sufficient progress is made.

Base Knowledge

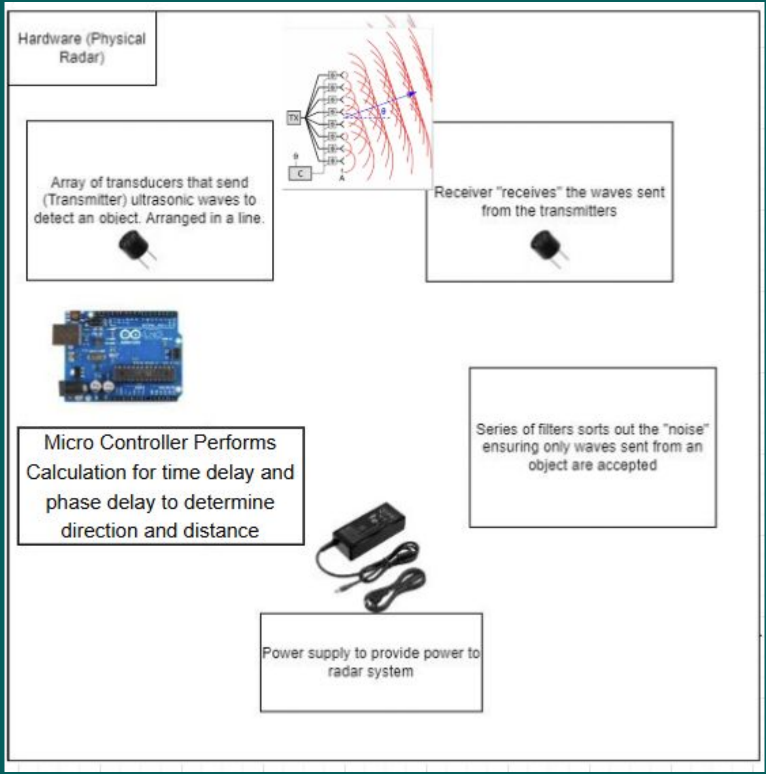
- To boost knowledge in this top we will consult, area experts (Professors), and related documents.
- Our group will also look over past group projects for information and insight

Areas of Concern

- Accurately sending, receiving, and subsequently processing a signal
  - Requires accurately depicting a mm measurement within the overall range of one meter.
  - The microcontroller, raspberry pi, and display will be required communicate efficiently and transfer data correctly.
  - With the data being processed and manipulated 3 times, we will have to make sure that everything works together smoothly.
- Creating a clear display
  - Ensuring the image is not muddy (if it is depicted with a heat map the streaks should not be exceedingly large)

Detailed Design Hardware

- The hardware describes the physical radar system
- The end goal of the hardware is to send angle determined by phase delay and the distance base on the time delay data to the Raspberry Pi
- The power supply powers the radar system.

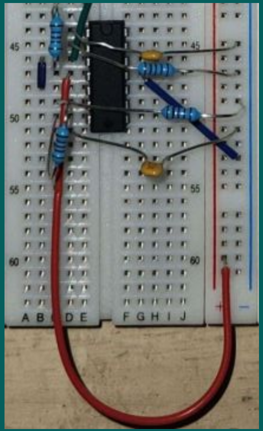


The MCU

- Using ESP32-S3-DevKitC-1-N8R8
- Sets the phase delay for the next pulse
  - focuses and determines the direction (angle) of the scan.
- The MCU determines the time delay based on the time a pulse is sent.
- The time delay is used to calculate the distance using the approximate speed of the pulse.
- It sends the distance and angle to the Raspberry PI

The Transducers And Filters

- The transmitters send ultrasonic waves that are used for object detection
  - Placed in a linear pattern to function as a phase array
- The receiver detects the waves that reflect off a detected object
- The filters remove the noise (remove the frequencies that are significantly out of range) to make the detection more accurate



Transmitter

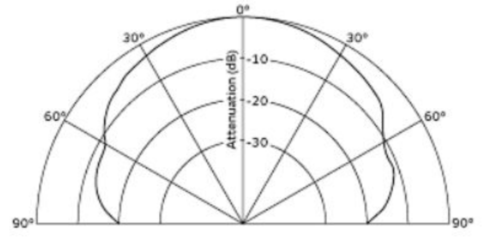


Fig.3 S.P.L.(MA40S4S)

Receiver

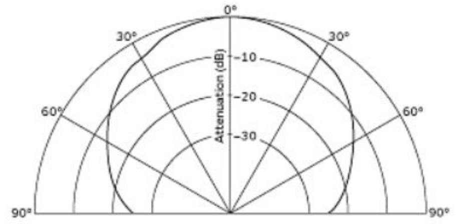
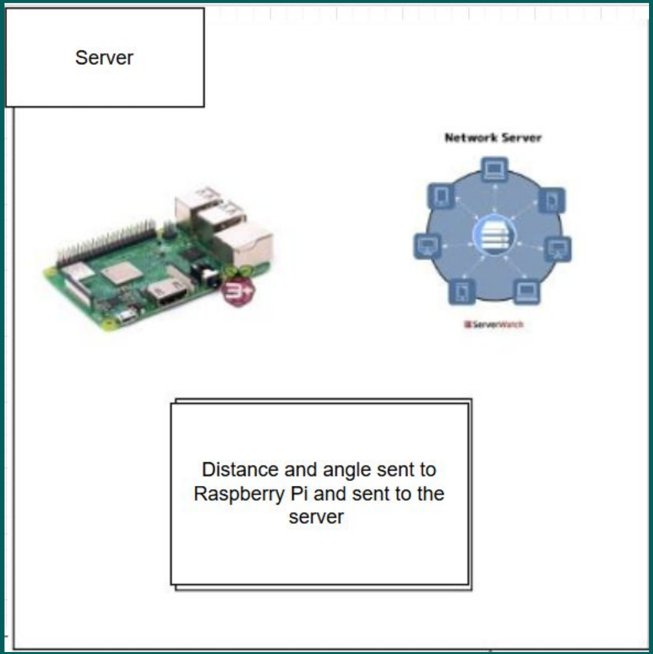


Fig.4 Sensitivity(MA40S4R)

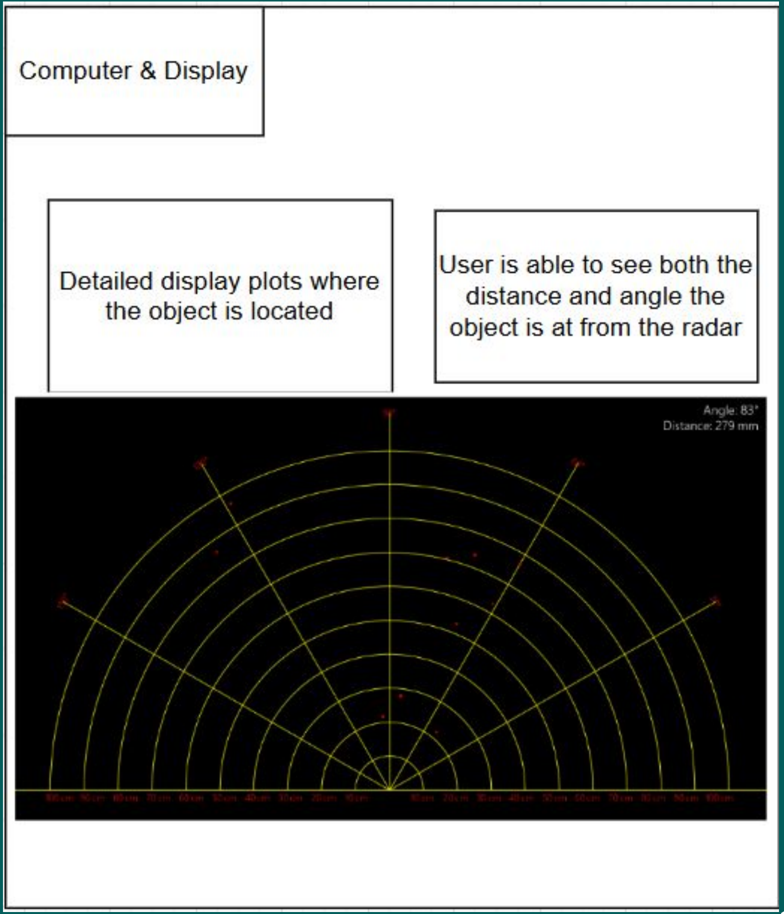
Detailed Design Server

- Raspberry Pi puts data on a web server to transfer to the computer to display.
- The server transmits data over a wireless connection.



Detailed Design Display

- Data is received from the Raspberry Pi and processed to create a user friendly display.
- The display will show an object's direction and distance.
- An object is depicted as a collection of points.



Technical Area and Complexities Hardware

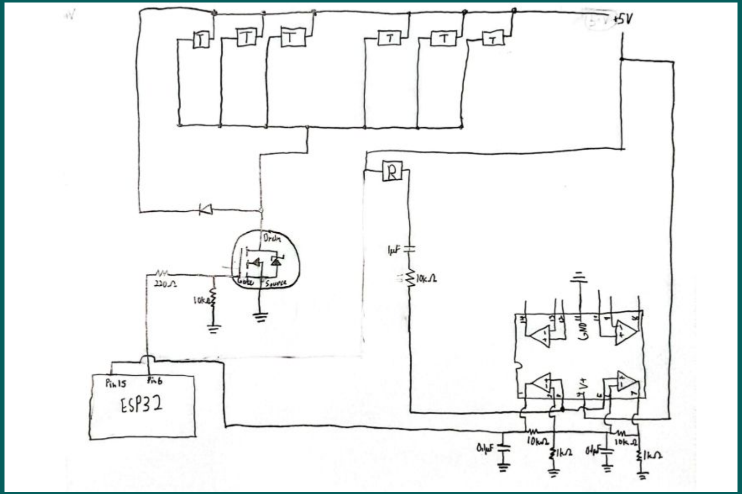
- Transmitter placement ensures transmitters are positioned to maximize the signal-to-noise ratio.
- Pulse input filtering incorporates filtering circuits to minimize noise and electromagnetic interference.
- Amplifier design adjusts the gain levels to strengthen the signals without amplifying noise.
- Receiver must be fine-tuned to accurately detect faint echoes.
- Circuit design ensures that the circuit avoids cross-talk and maintains signal integrity.
- Component integration aligns transmitter and receiver characteristics to ensure compatibility.

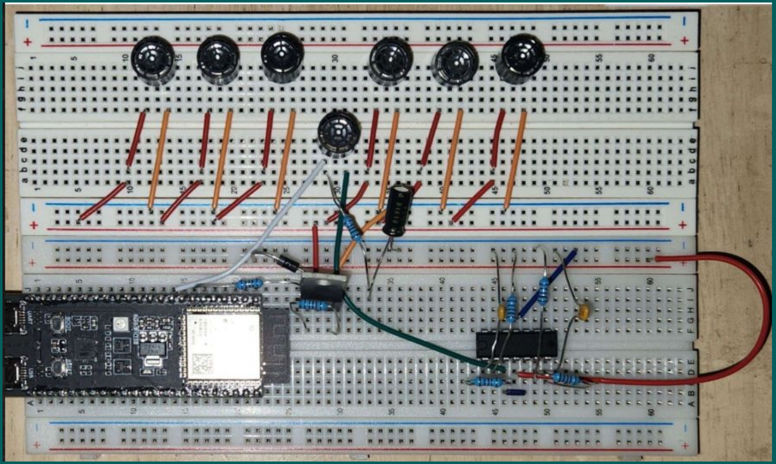
Technical Area and Complexities Software

- Must accurately account for phase delay for series of transmitters (10).
- Must combine readings from multiple receivers.
- Data must be received, parsed, and sent to the Raspberry Pi in a timely manner
- Display will need to know when new data is sent to the server to accurately display data
- There must be a clear difference between objects

Prototype (Radar)

- Our hardware prototype consists of testing to make sure the sensor can send and receive signals.
    - Currently we have only been testing with 6 transmitters(All go off at same time to)





Display Demonstration

- Displayed randomly generated data to simulate object detection
- Older points become faded to represent relative time of read (readings are limited to 10 at a time in this video)
- Displays current reading in top right corner
- Angles are labeled in 30 degree increments and distance in 10 cm increments

Next Steps (Display)

- Have mouse location be tracked displaying coordinate being hovered on.
  - Allows the viewer to understand the location of prior detections
- Highlight the effective FOV which is expected to be approximately 80 degrees (40 degrees in either direction).
- Determine an efficient method (must not lead to major delays) for object grouping. This may include grouping readings with close proximity based on point color
- The display must be changed to read from the Raspberry Pi server
- Minor changes must be made to improve the readability of labels

Next Steps (Radar)

- Implementing phase delay to take advantage of constructive interference to improve signal to noise ratio for readings.
- Processing data to follow easy to use format for the computer to use for the display.
- Transmit data values to the Raspberry Pi server through Wifi.
- Design additional filters to remove unwanted frequencies, and clean the received signal.

Future Implications

- Determine the exact number of receivers to use (before benefits become marginal)
- Potentially migrate the display to C++ with OpenGL or SFML for faster data processing
- Use concurrency to implement phase pulses (potentially using Coroutines)
- Consider expanding radar range based on image clarity

Ideals

Performing Well:

- Financial
  - Taking price into consideration, when selecting parts, opting for the cheapest component of sufficient performance..
  - The total cost of components currently is $69.79
  - We will handle the components with responsibility to avoid additional costs

Could Improve:

- **Health, Safety, and Wellbeing**
  - High sound intensity from the transducers.
    - Has an output of 120 dB, this can cause hearing loss.
    - To help solve this issue we will undervolt the transducers to reduce the sound intensity.
    - We will provide a warning to not stand too close to the device, and to use ear protection if the voltage is set to its max value.

Questions?