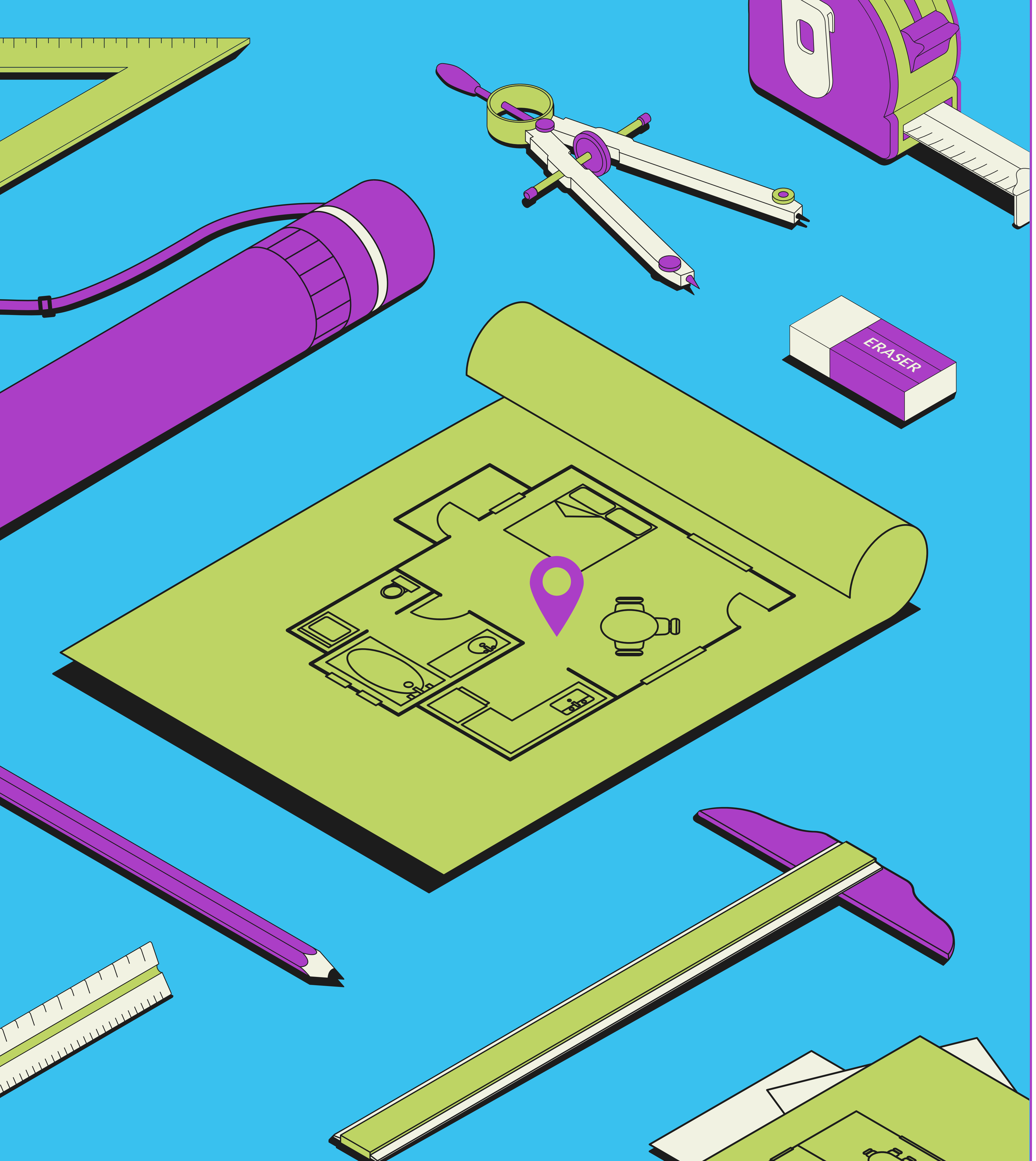


UltraGPS

Indoor Positioning System

By: Nnamdi Jesse Onwuzurike


CAR POV


WORLD VIEW

ULTRAGPS

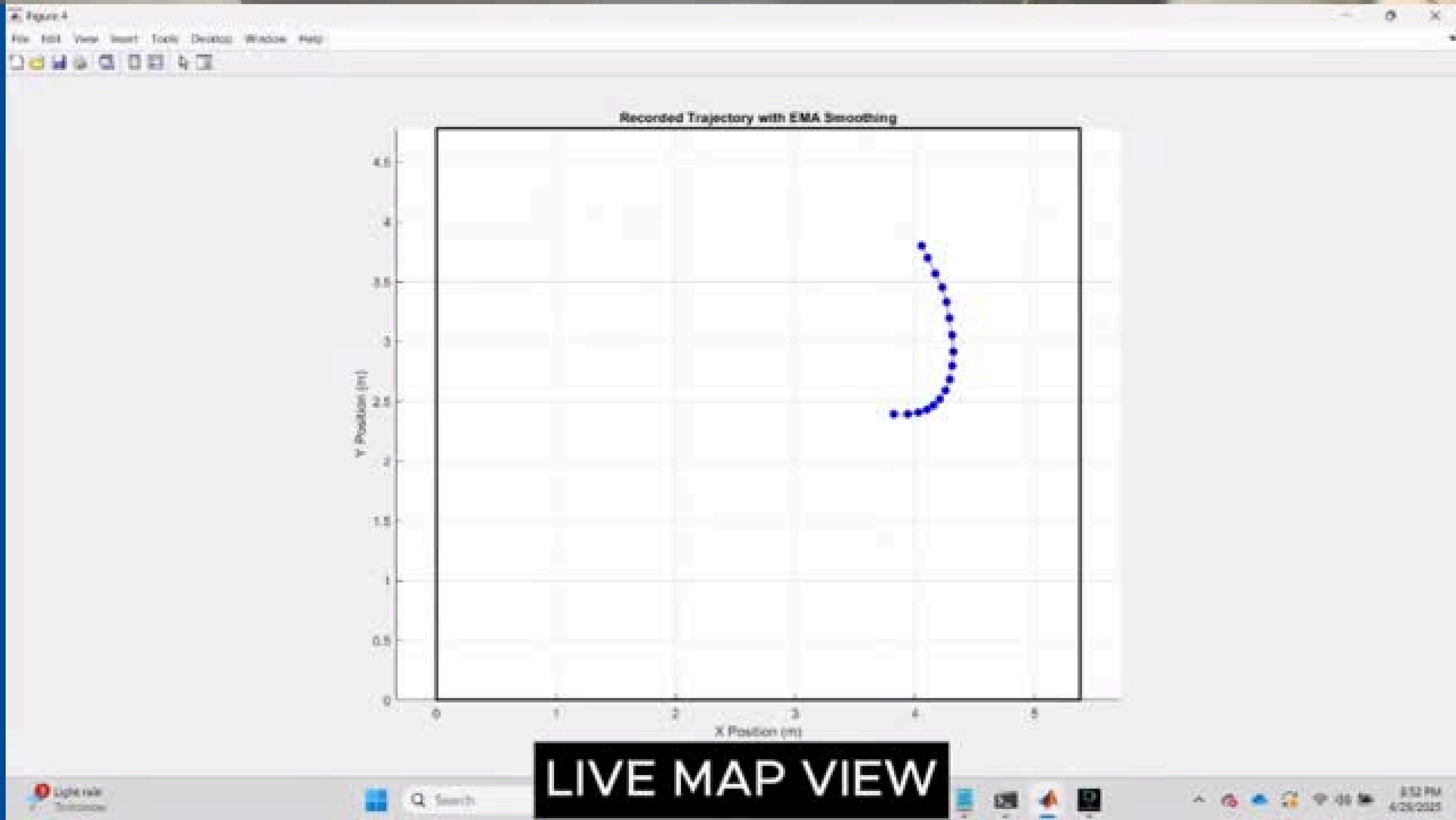


Figure 4
File Edit View Insert Tools Desktop Window Help
Recorded Trajectory with EMA Smoothing
Y Position (m)
X Position (m)
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
0 1 2 3 4 5
LIVE MAP VIEW

PROBLEM STATEMENT

The Problem

GPS is unreliable indoors

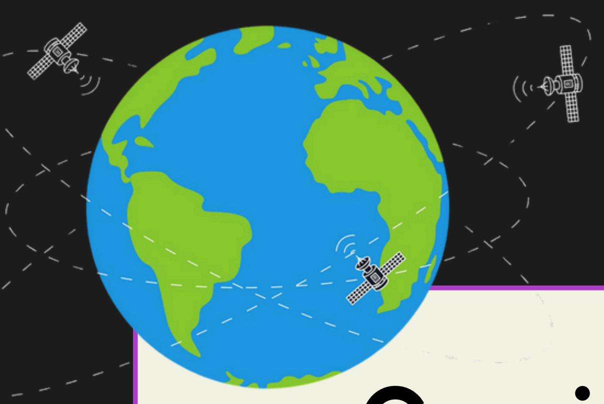
Current indoor solutions are too expensive

Our Solution

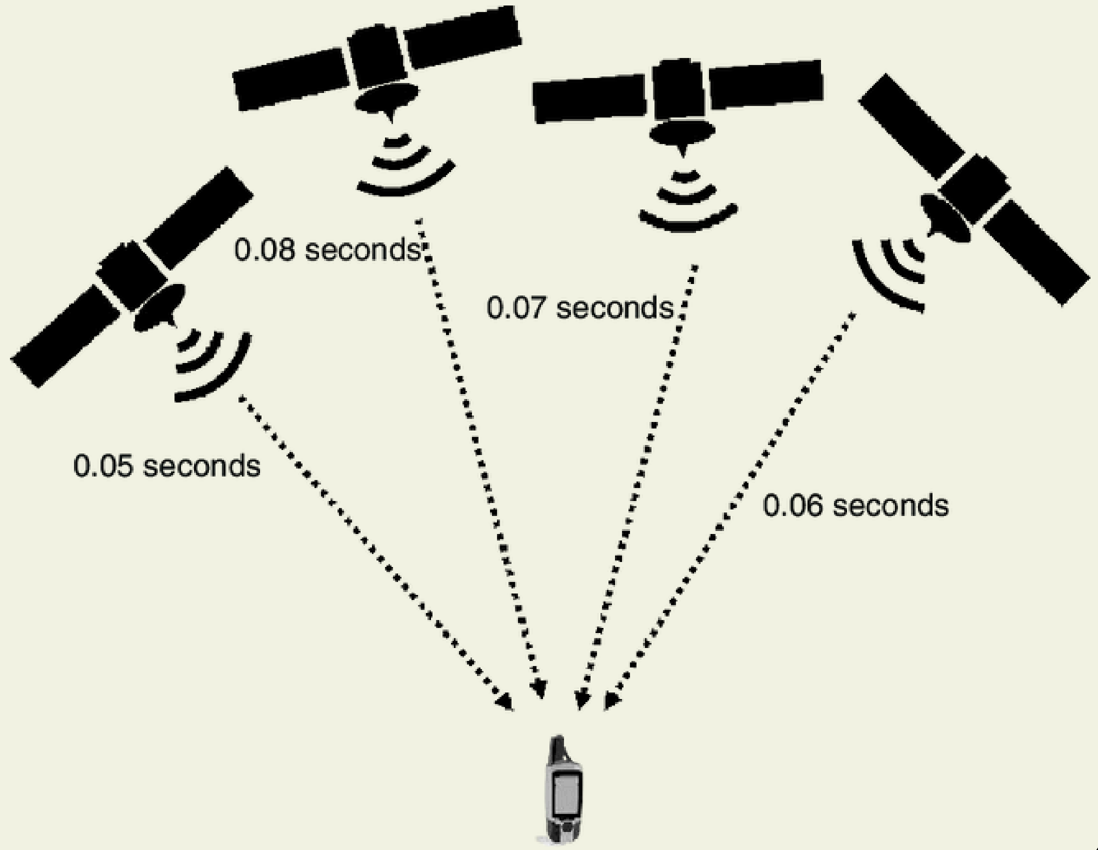
Cost-effective, ultrasound-based indoor positioning system:

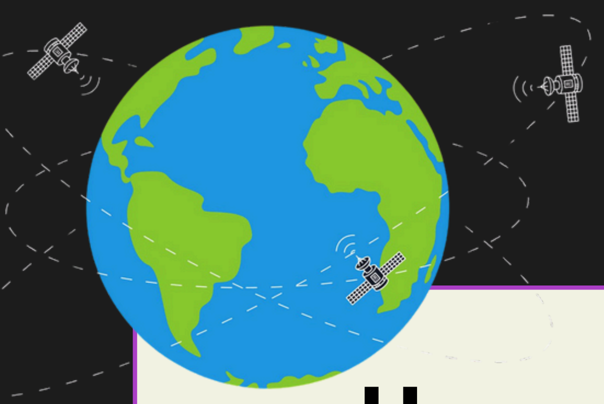
ULTRA GPS

HOW DOES GPS WORK?



- **Consists** of 24 satellites orbiting Earth.
- Each satellite **transmits** signals with time and location data.
- A receiver **picks up** signals from multiple satellites.
- It **needs** signals from at least 4 satellites to determine an accurate position.
- **Measuring** the time delay between signal transmission and reception, it **calculates** the distance to each satellite.
- It **uses** trilateration to pinpoint latitude, longitude, and altitude.



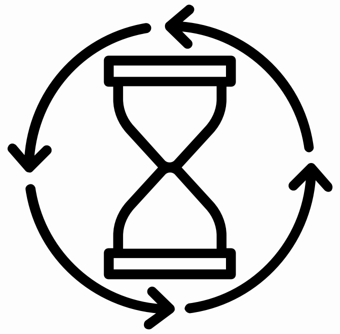


HOW DOES ULTRAGPS WORK?

- **Uses** a technique called **Reverse GPS**
- Transmitters are **placed** on the object you want to track
- This transmitter **emits** a signal
- Multiple fixed receivers are **placed** around the environment.
- Each receiver **records** the time the signal arrives.
- With that, the system **calculates distances** from the transmitter to each receiver.
- The system then **performs trilateration** to determine the exact location of the transmitter

SYSTEM REQUIREMENTS

Achieve within 5 cm accuracy.

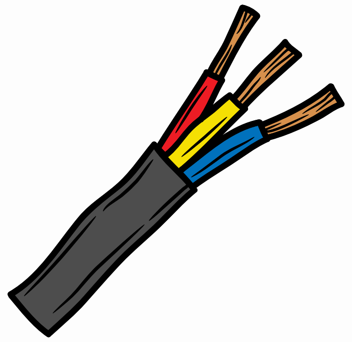


The update rate must be 5 Hz or more.

Calibration and setup must take ≤10 minutes.

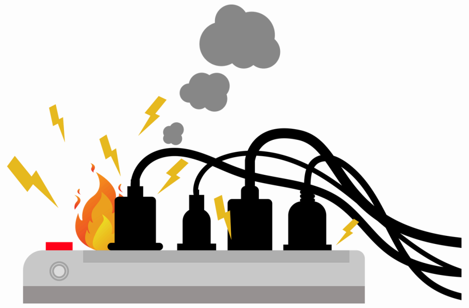
Maintain accurate localization even with obstacles present.

Function effectively within a standard school gymnasium.



Use a stable wired connection between system interfaces.

SYSTEM CONSTRAINTS



Minimize onboard power consumption.

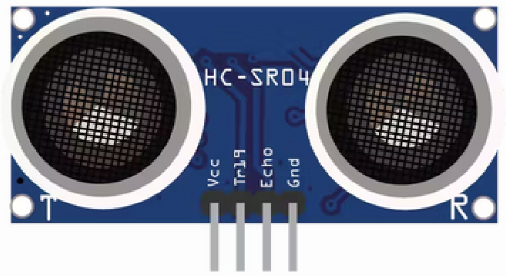
Receiver set should cost ≤$500.

Transmitter must cost ≤$100 per platform.

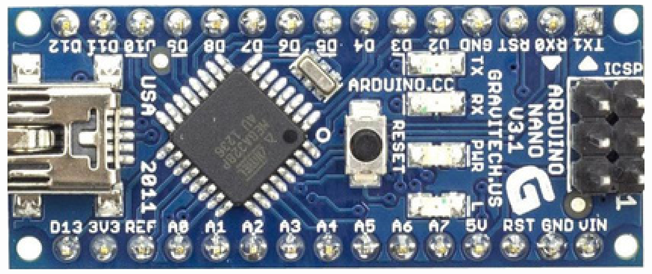
Must not interfere with onboard sensors.

Must not affect vehicle dynamics.

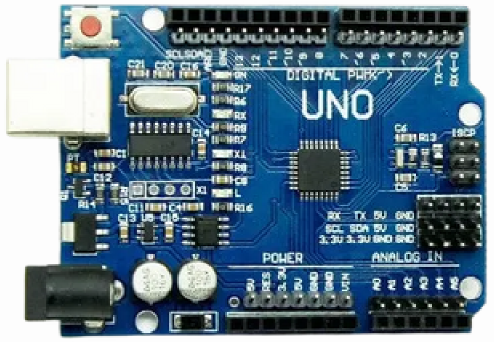
HARDWARE DESIGN COMPONENTS



HC-SR04 Ultrasonic Distance Sensor



Arduino Nano Microcontroller



Arduino Uno Microcontroller *

CAT5 Ethernet Cables

nRF24L01 Transceiver Module

SOFTWARE TOOLS

Arduino IDE

C++ programming environment for TX and RX Arduino systems

Canva

Used to design this presentation and system visuals

Lucidchart

For system diagrams and functional workflows

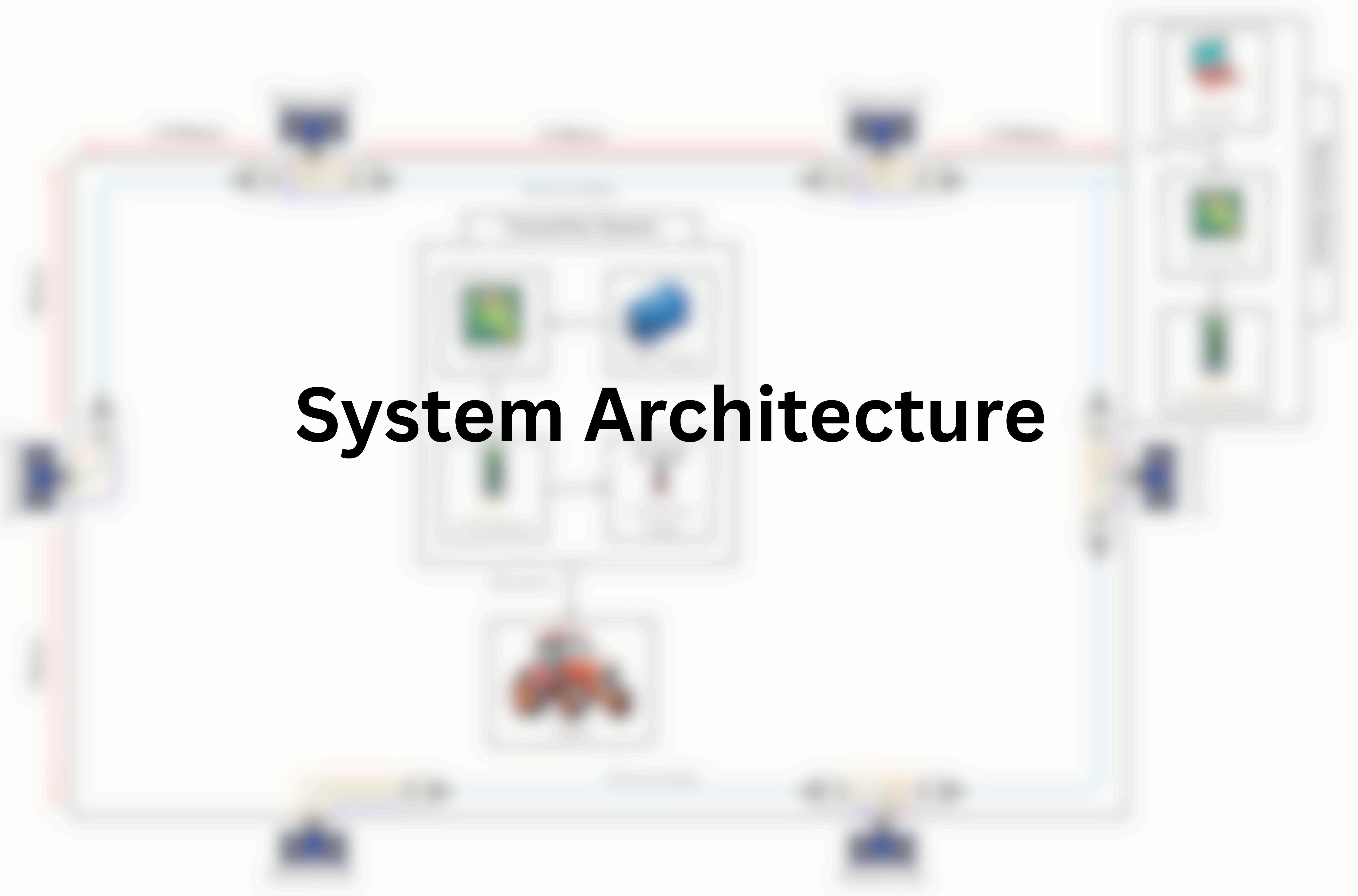
MATLAB

Used for trilateration, least squares estimation, and real-time position calculation

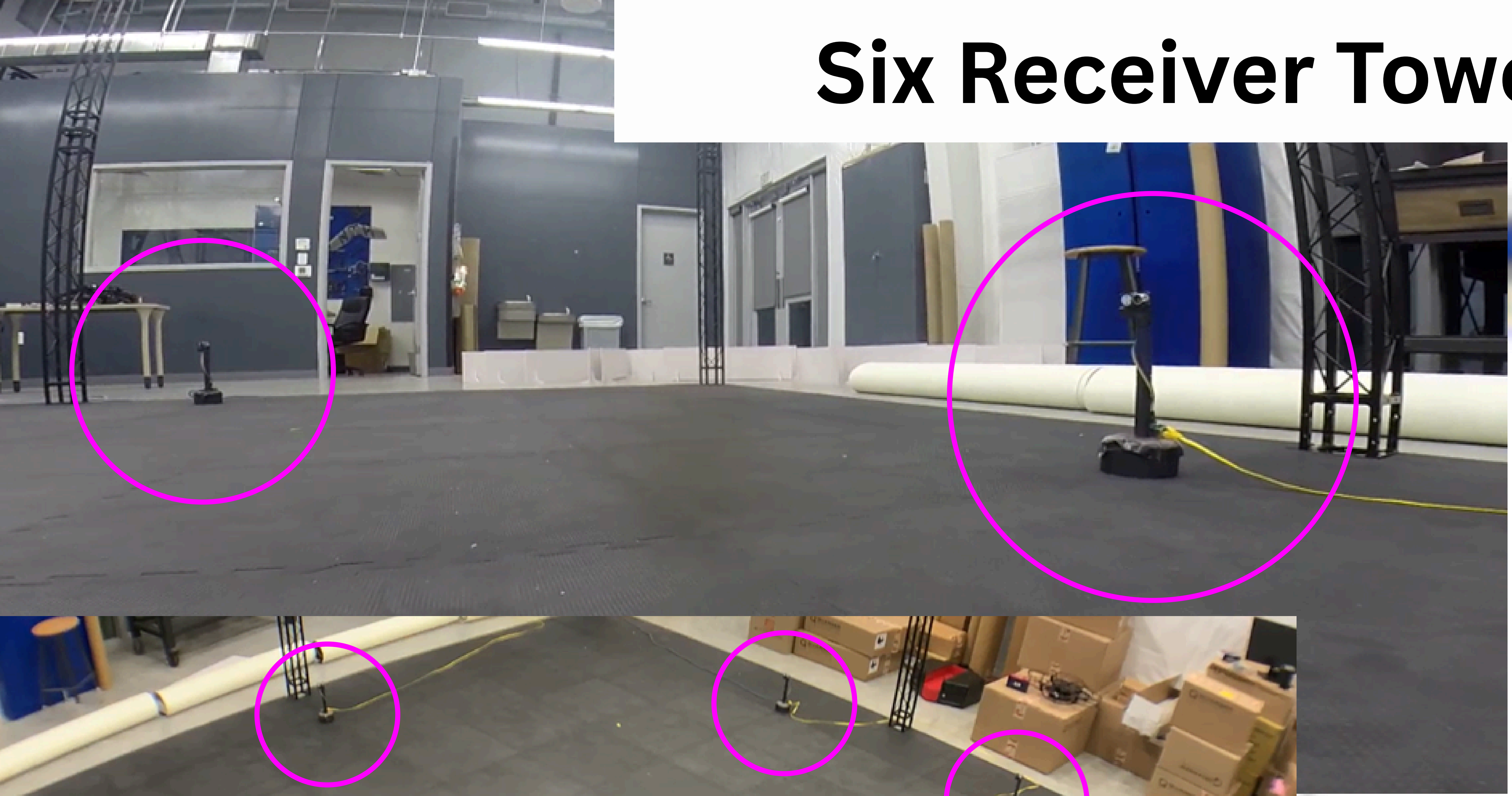
Solidworks

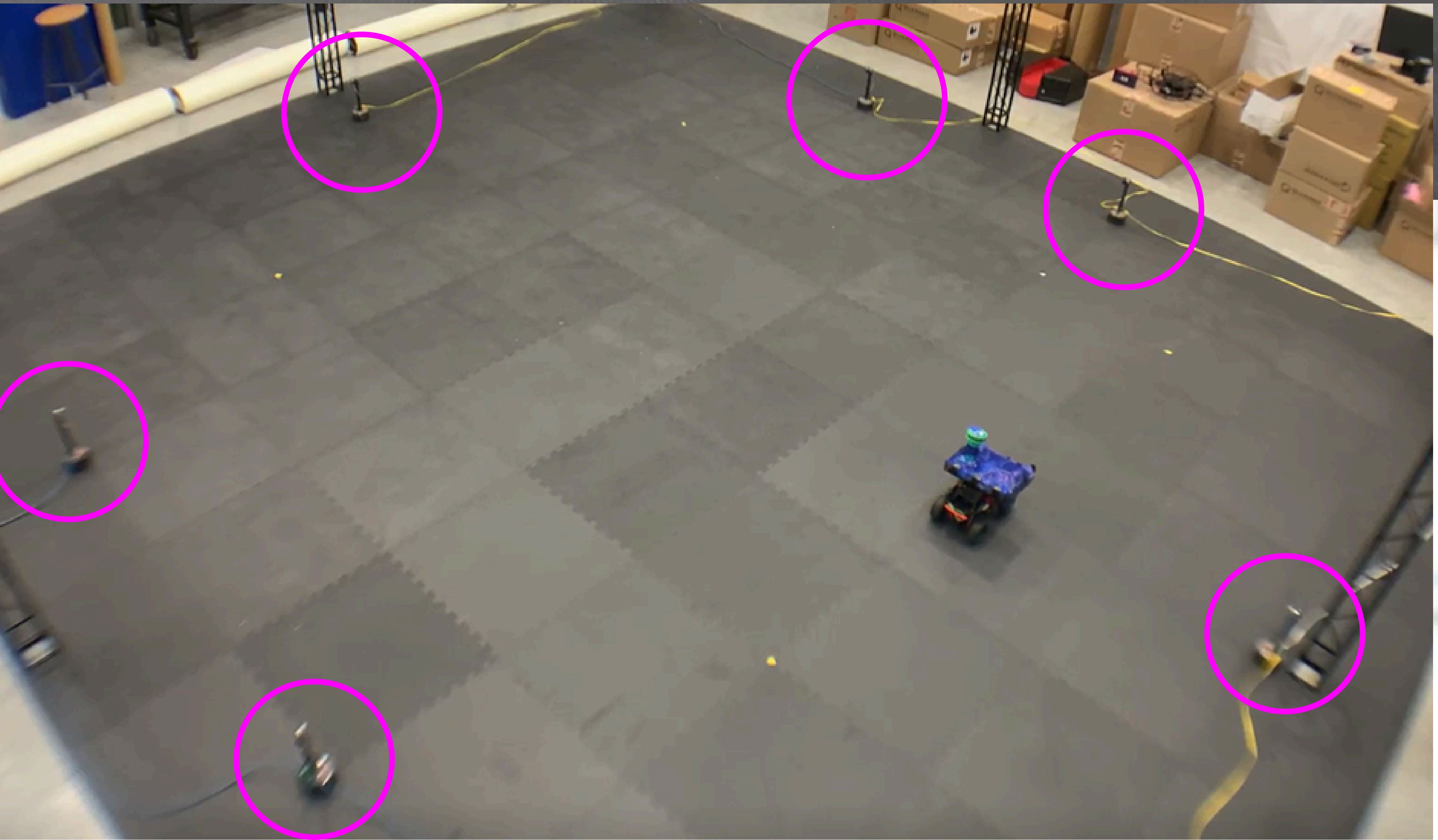
Used to design 3D-printed components

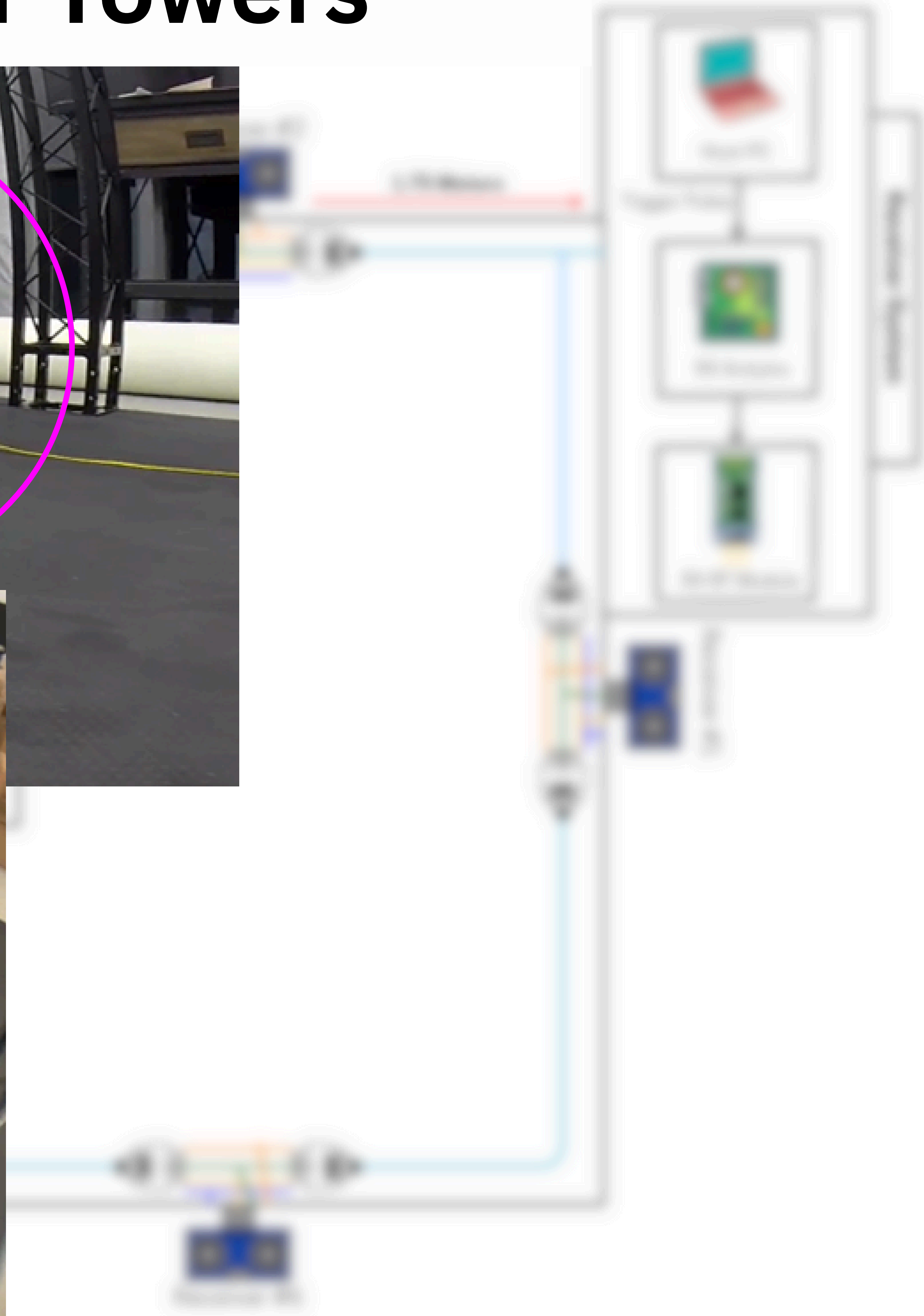
System Architecture



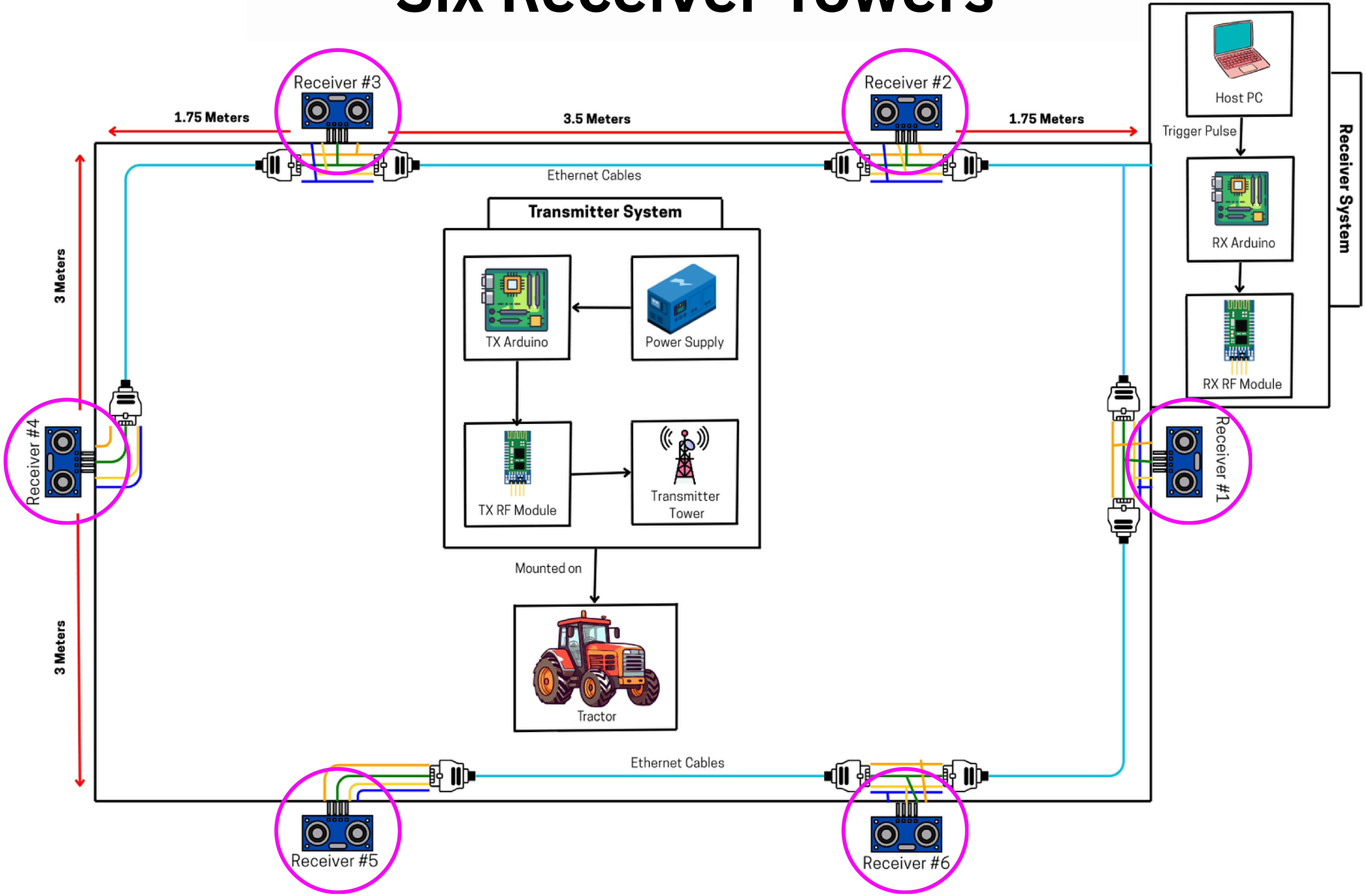
Six Receiver Towers



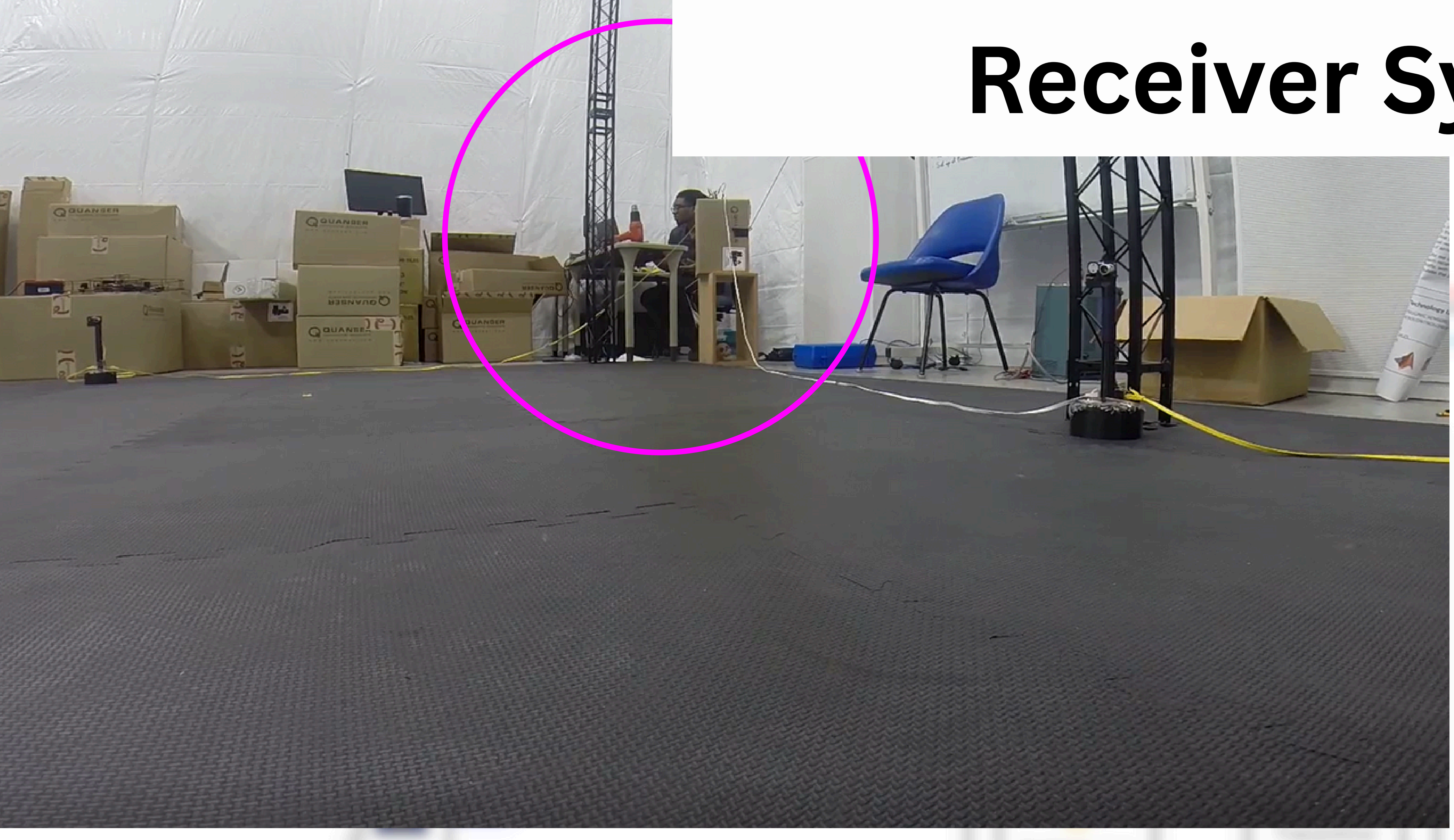


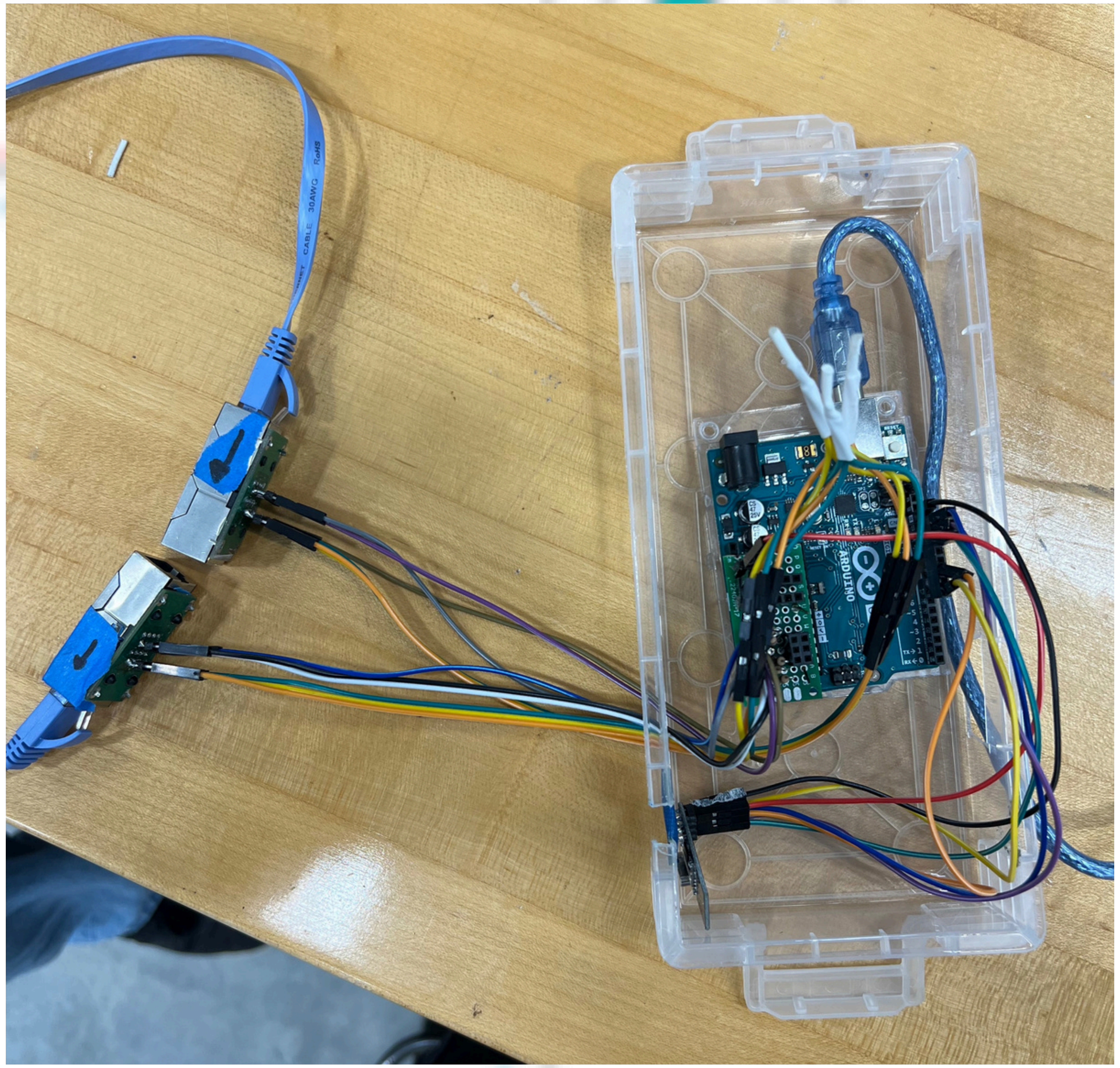


Six Receiver Towers

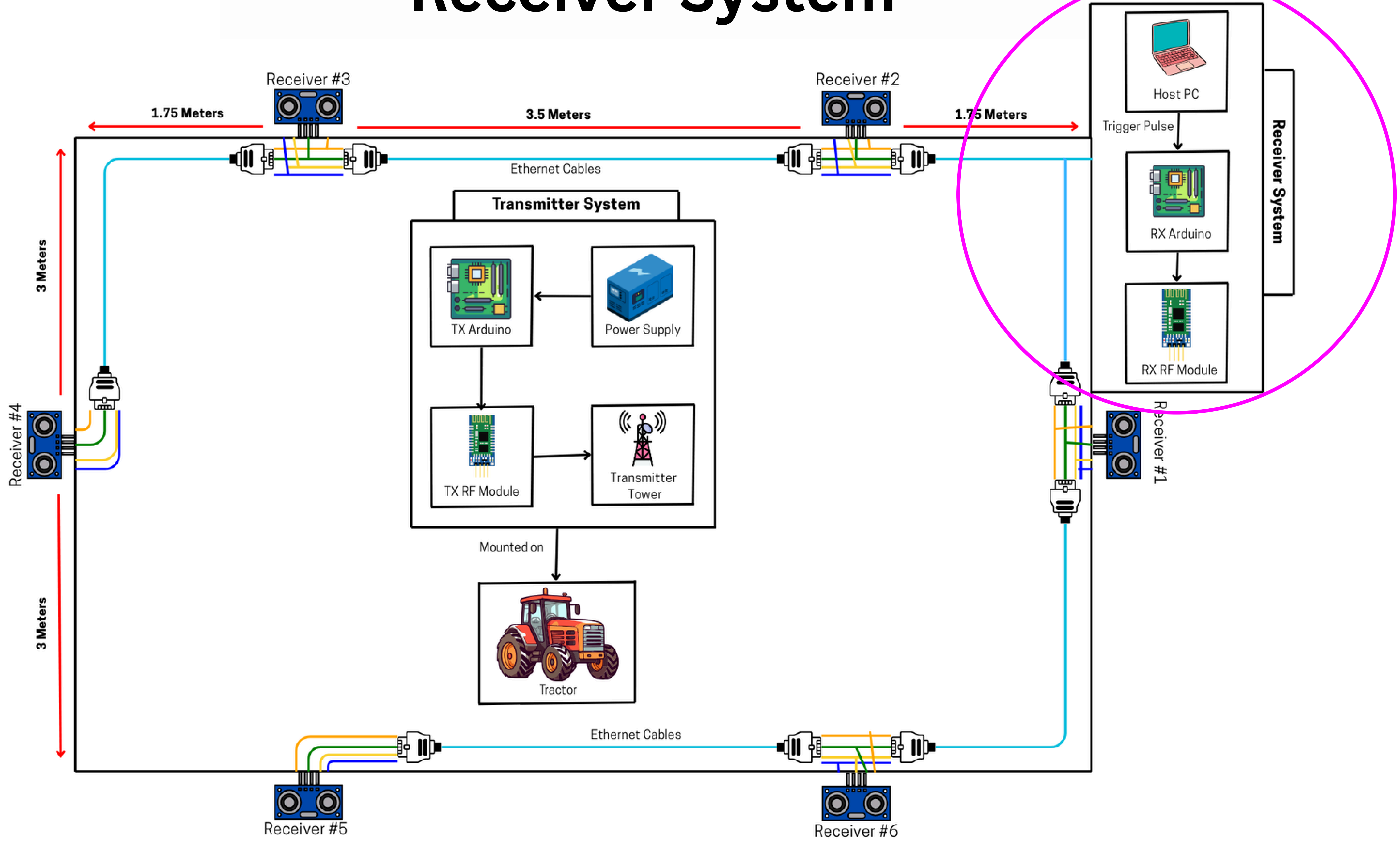


Receiver System

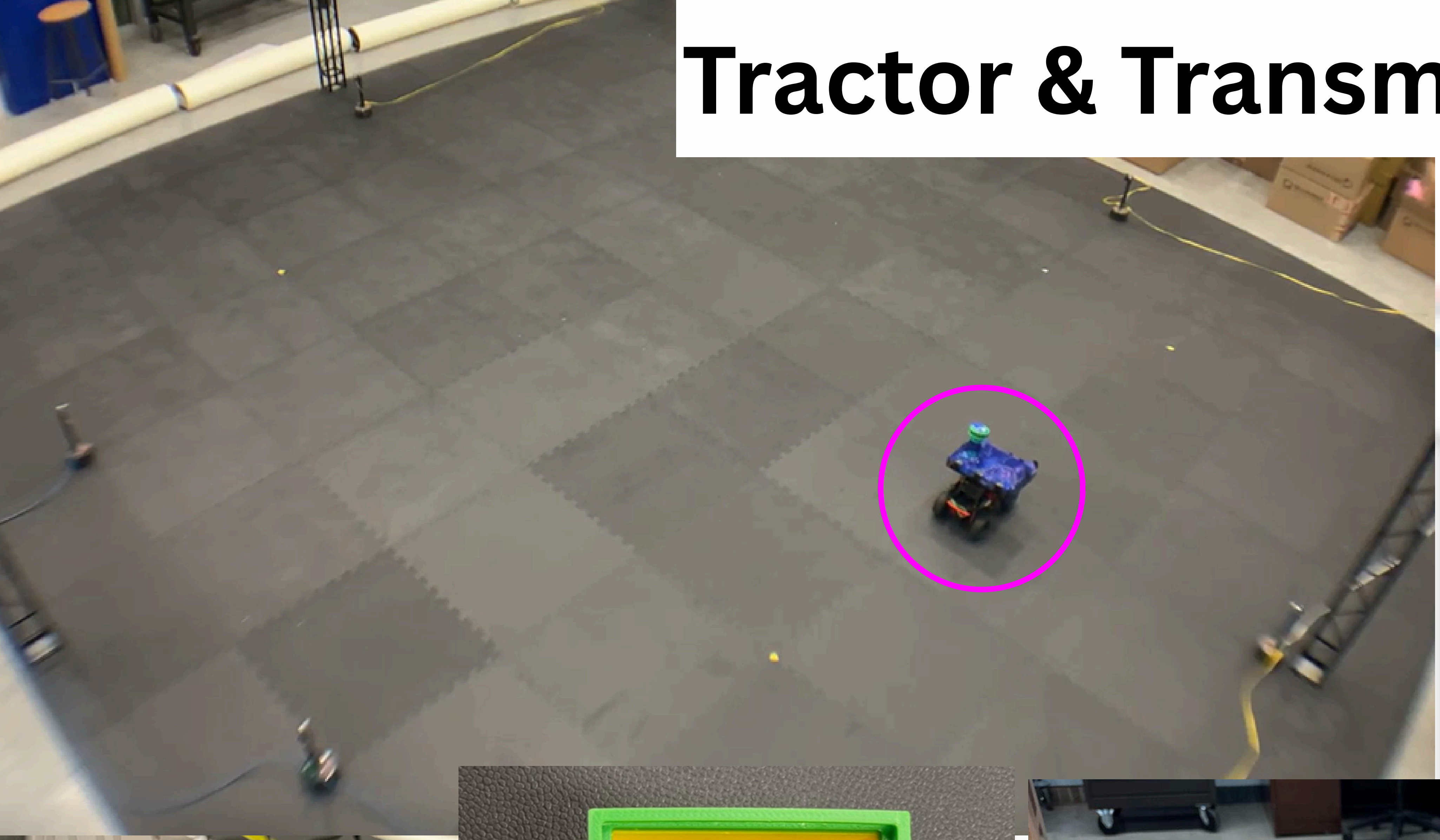


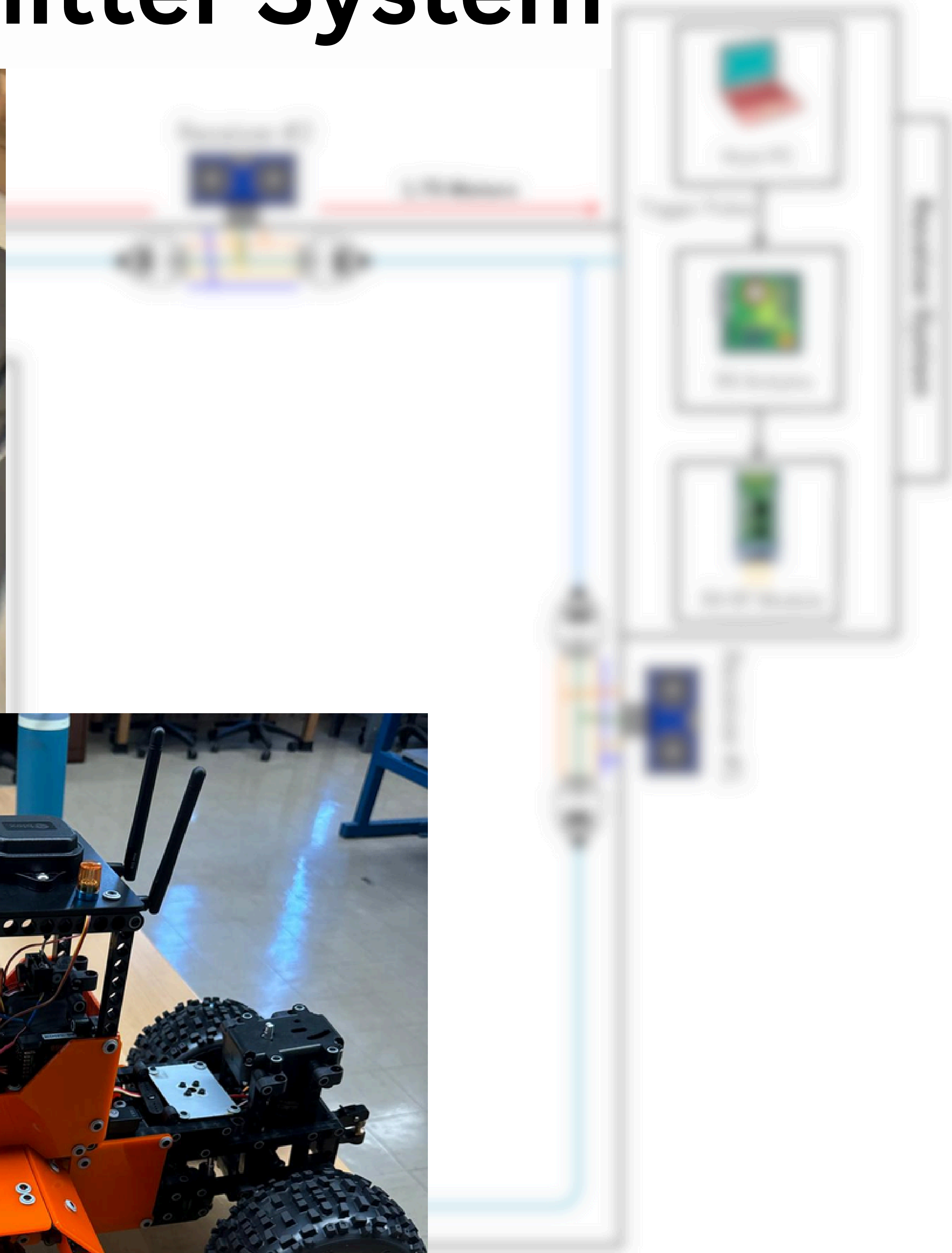


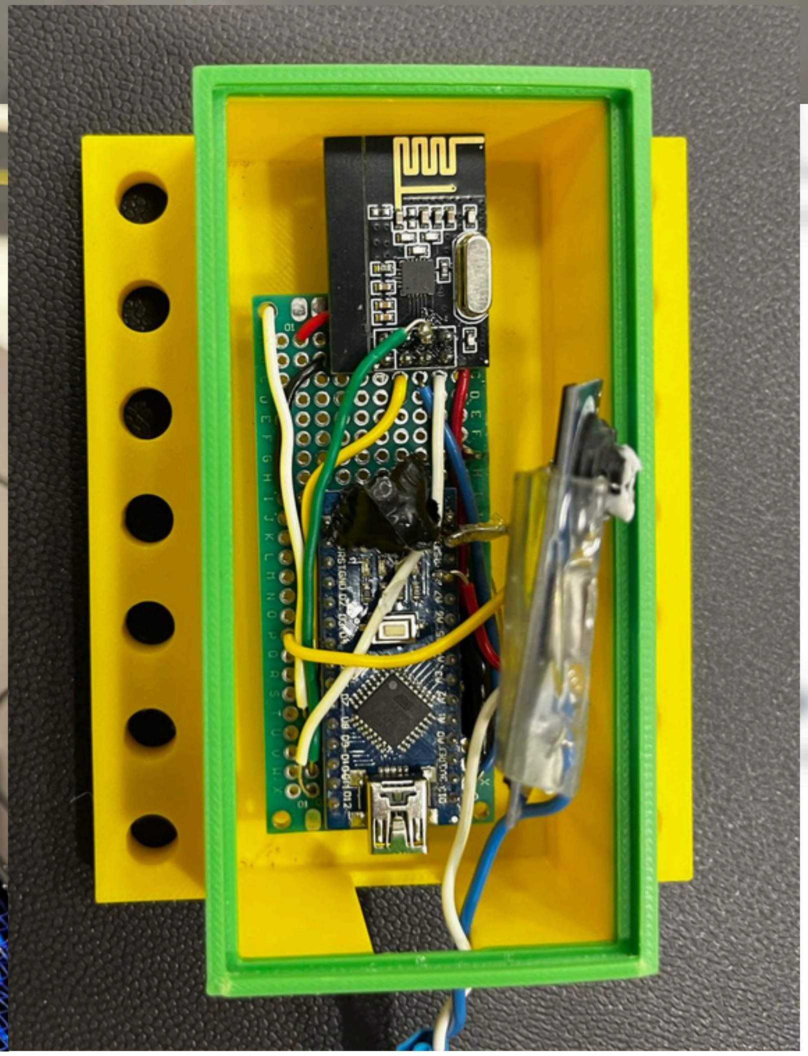
Receiver System



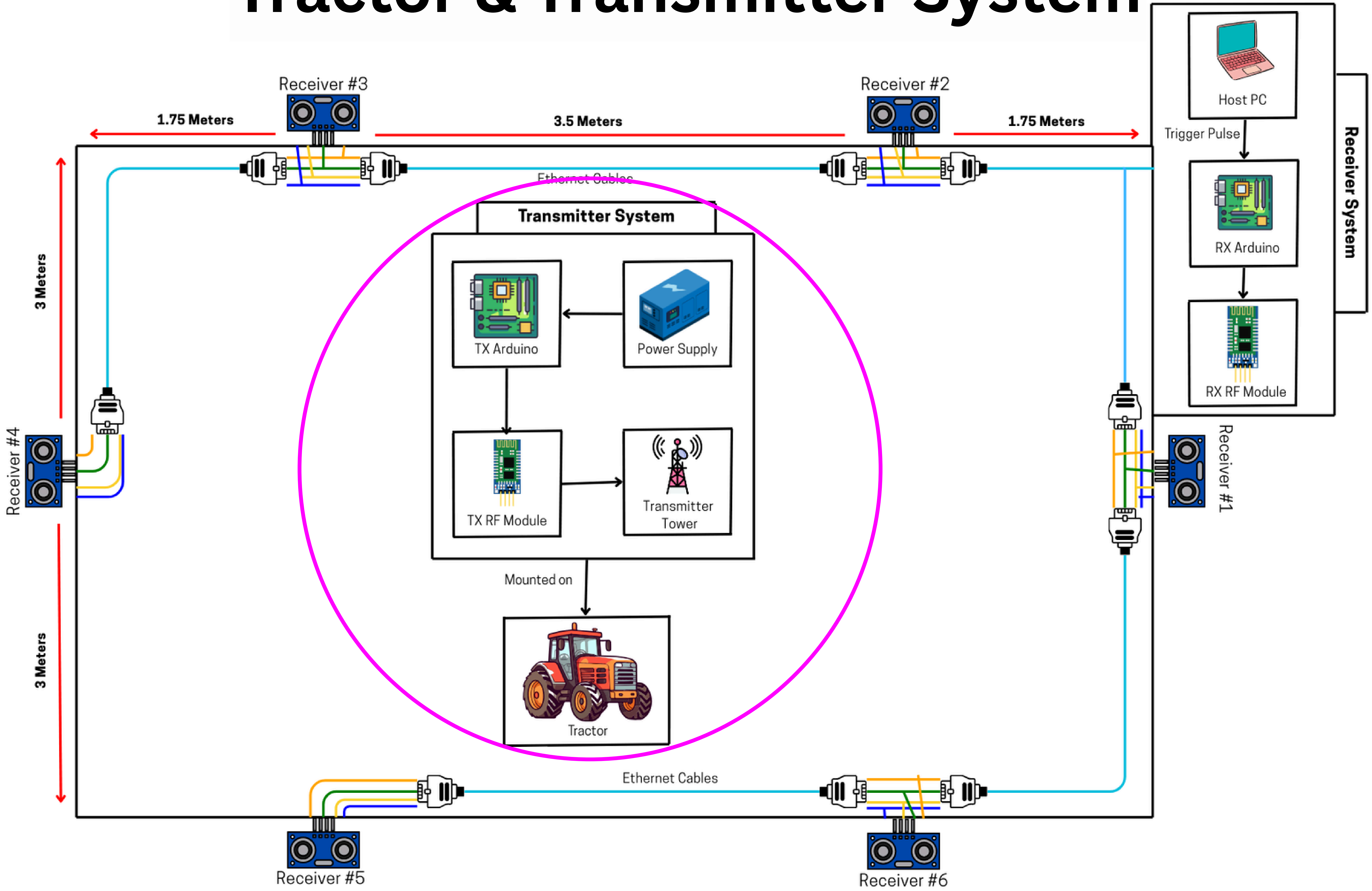
Tractor & Transmitter System



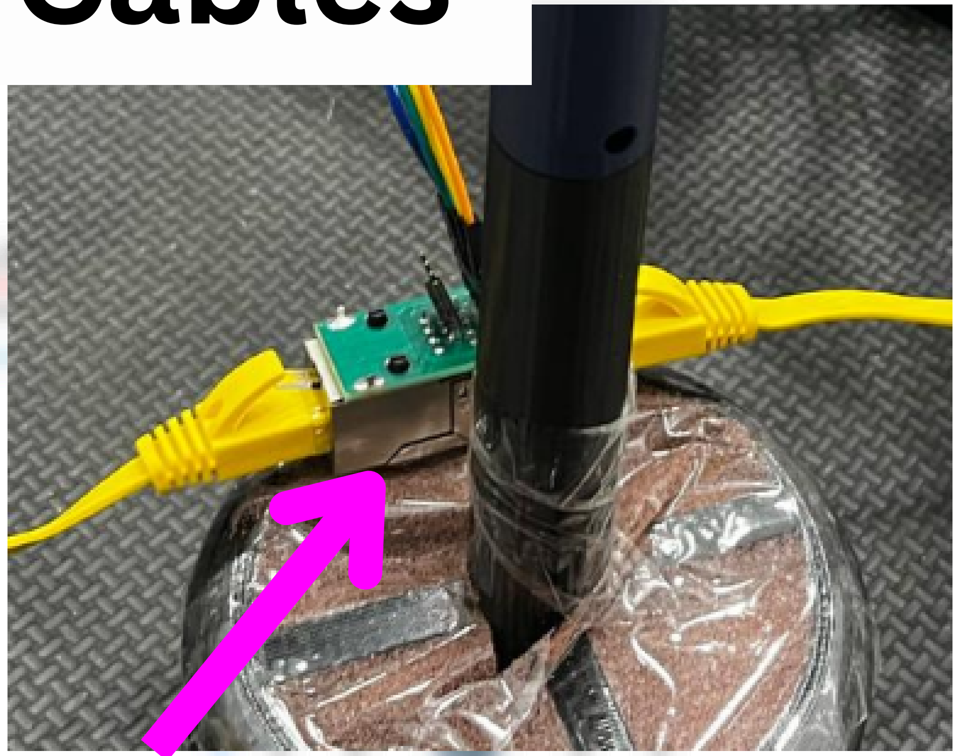




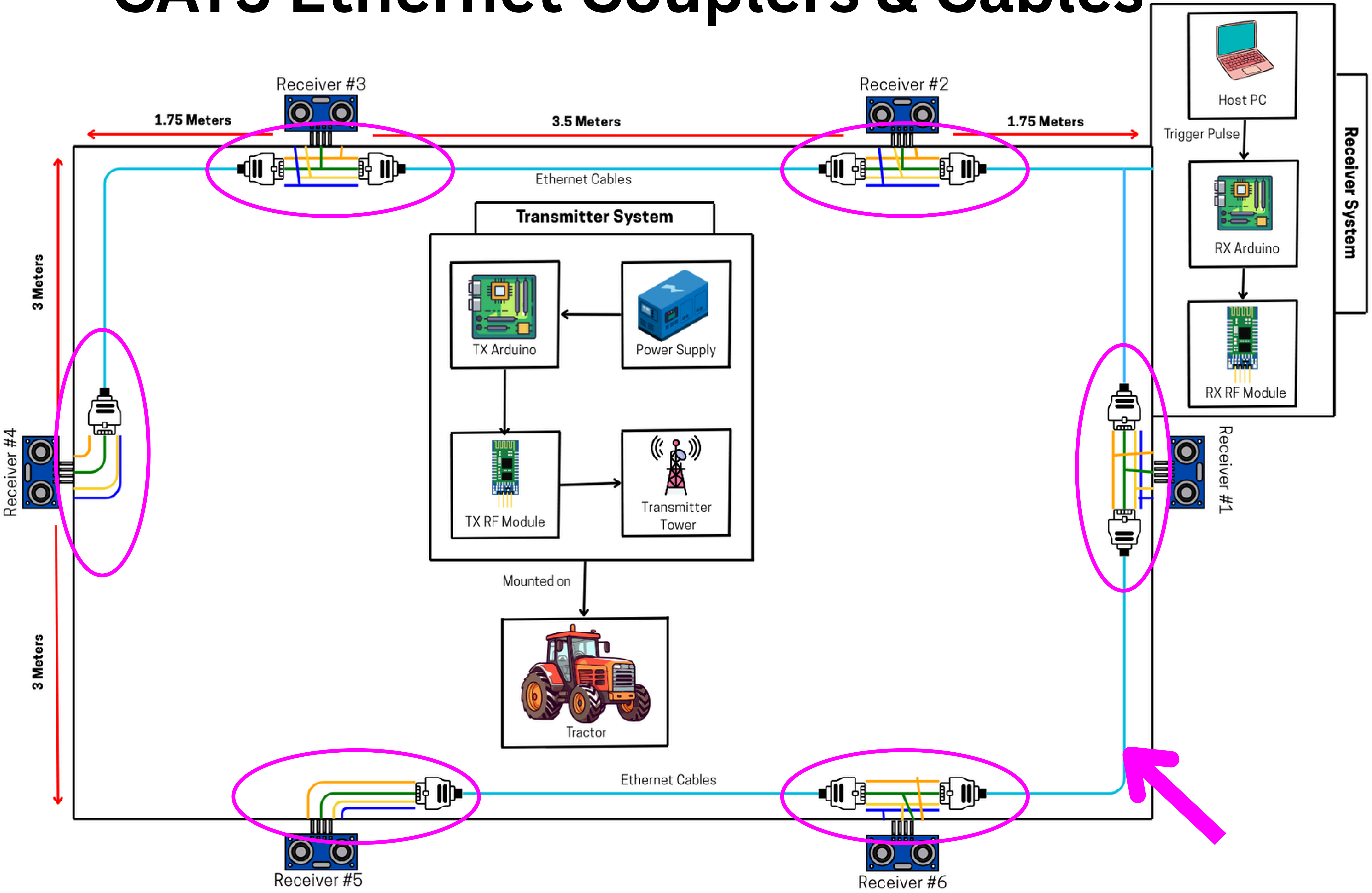
Tractor & Transmitter System



CAT5 Ethernet Couplers and Cables



CAT5 Ethernet Couplers & Cables

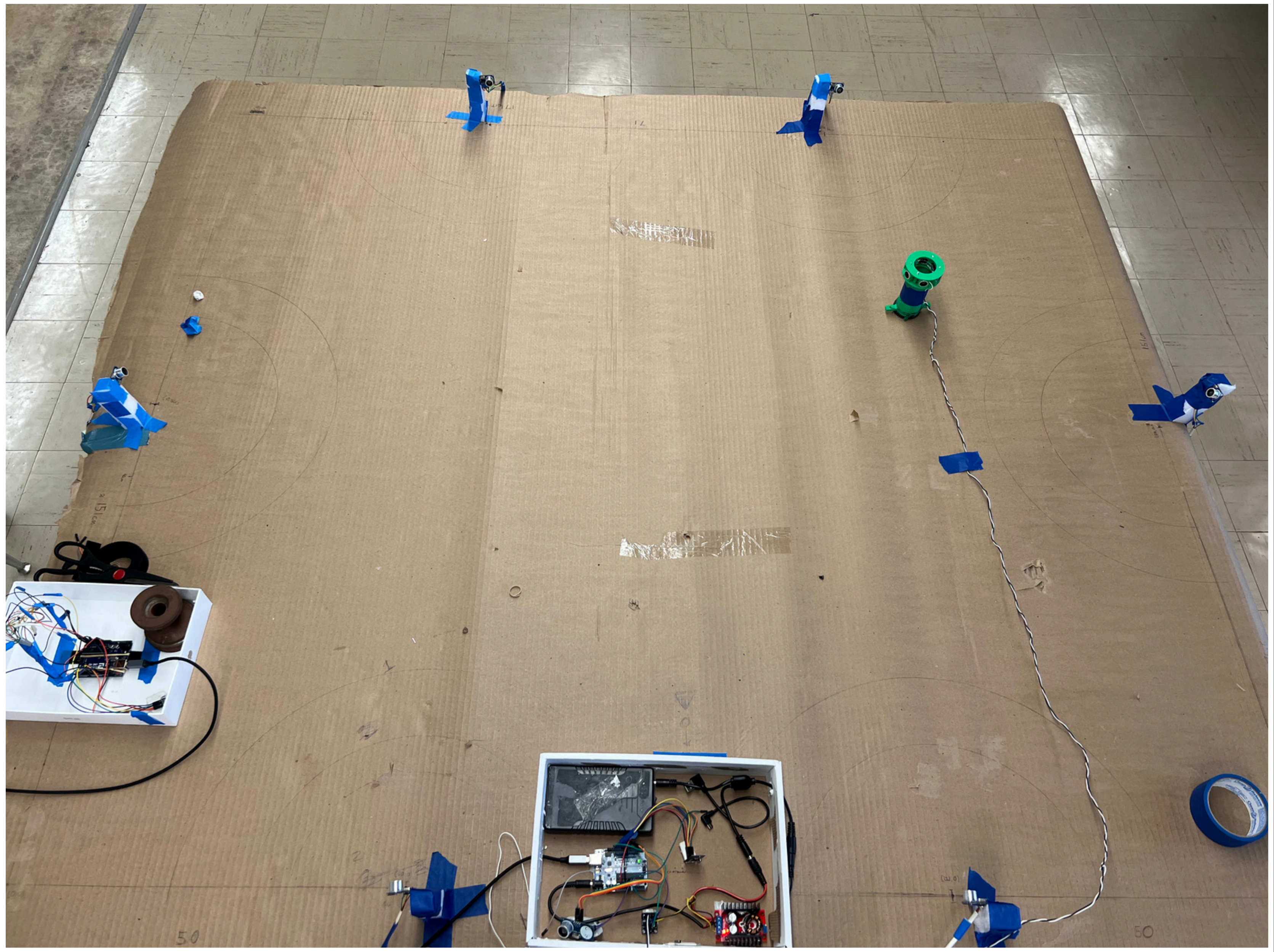


Bill of Materials & Budget Summary

Component	Unit Cost	Quantity	Total Cost	Notes
HC-SR04 Ultrasonic Sensors	$2.00	7	$14.00	6 TX, 6 RX
Arduino Nano	$2.50	2	$5.00	RX Arduino & TX Arduino
nRF24L01 Radio Modules	$3.00	2	$6.00	TX & RX synchronization
CAT5 Ethernet Cables	*$0.00*	6 to 10	*$0.00*	*Commonly found in schools; often unused*
3D Printed Mounts / Towers	*$0.00*	8	*$0.00*	*Printed in-house with PLA*
USB Battery Pack / Power Supply	$15.00	1	$15.00	Supply the TX Arduino
CAT5 Ethernet Coupler	$1.50	8	$12.00	Connects Ethernet to Receiver
Estimated System Total	-	-	$52	Cost-effective

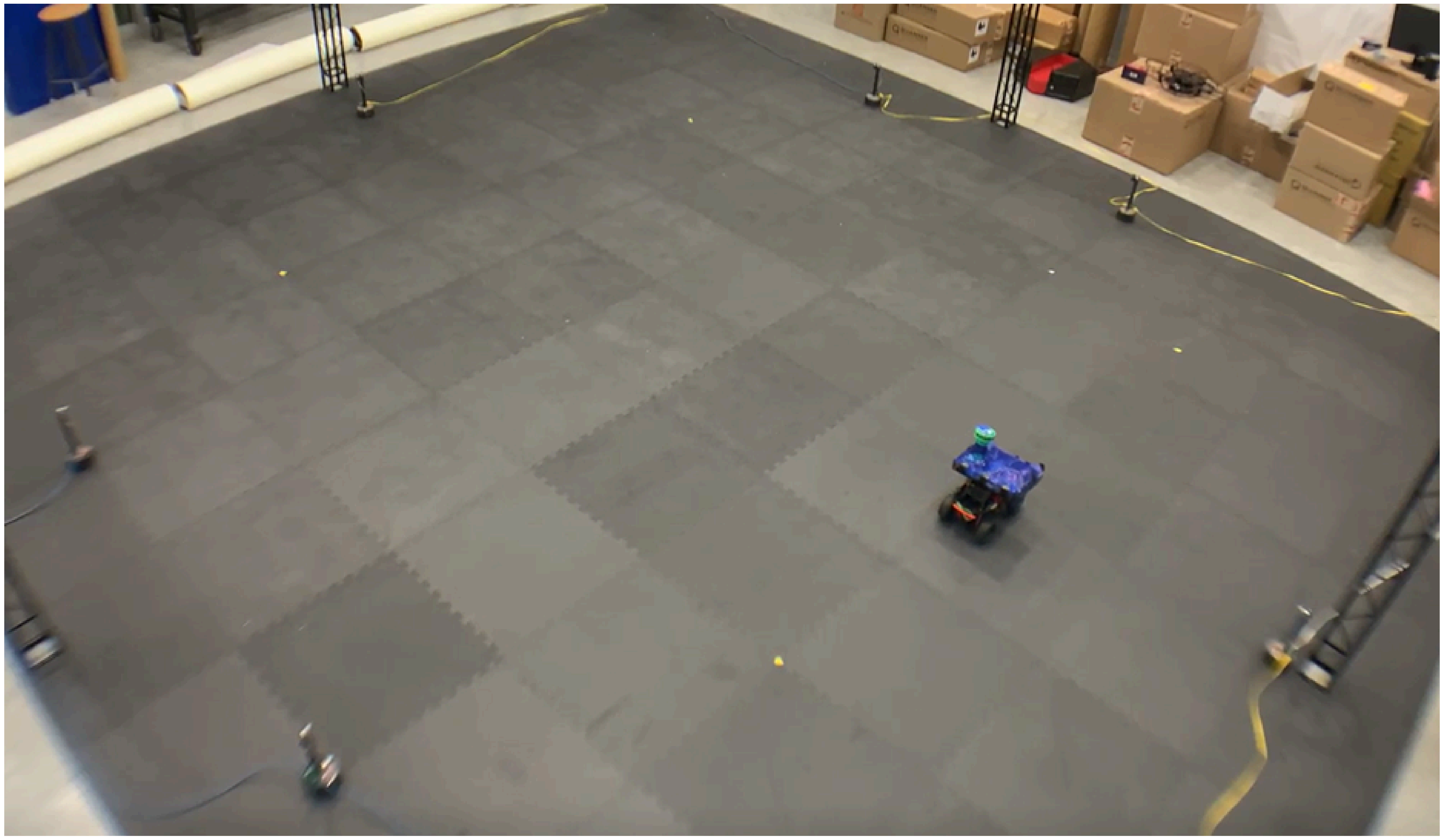
DESIGN ITERATIONS

SETUP #1

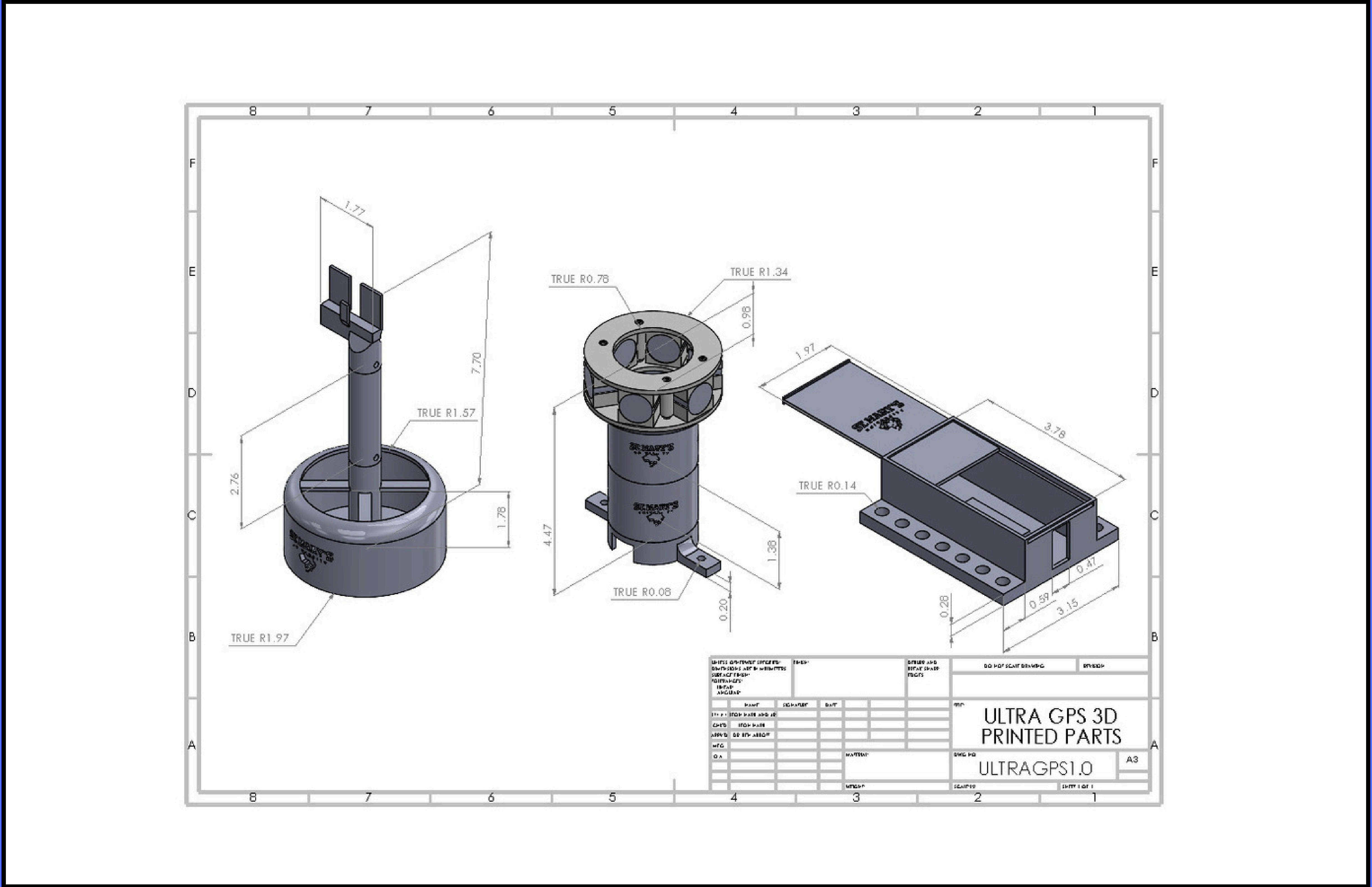


SETUP #2

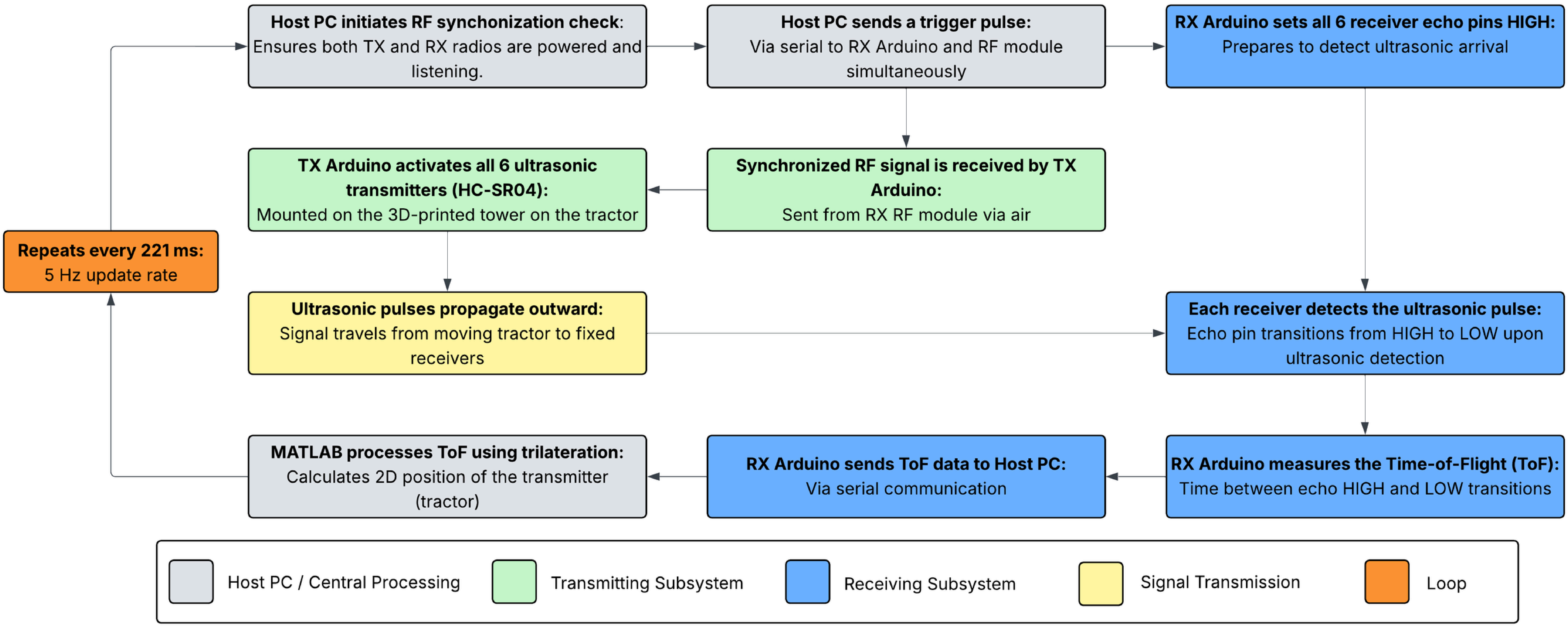
SETUP #3



3D-PRINTED COMPONENTS

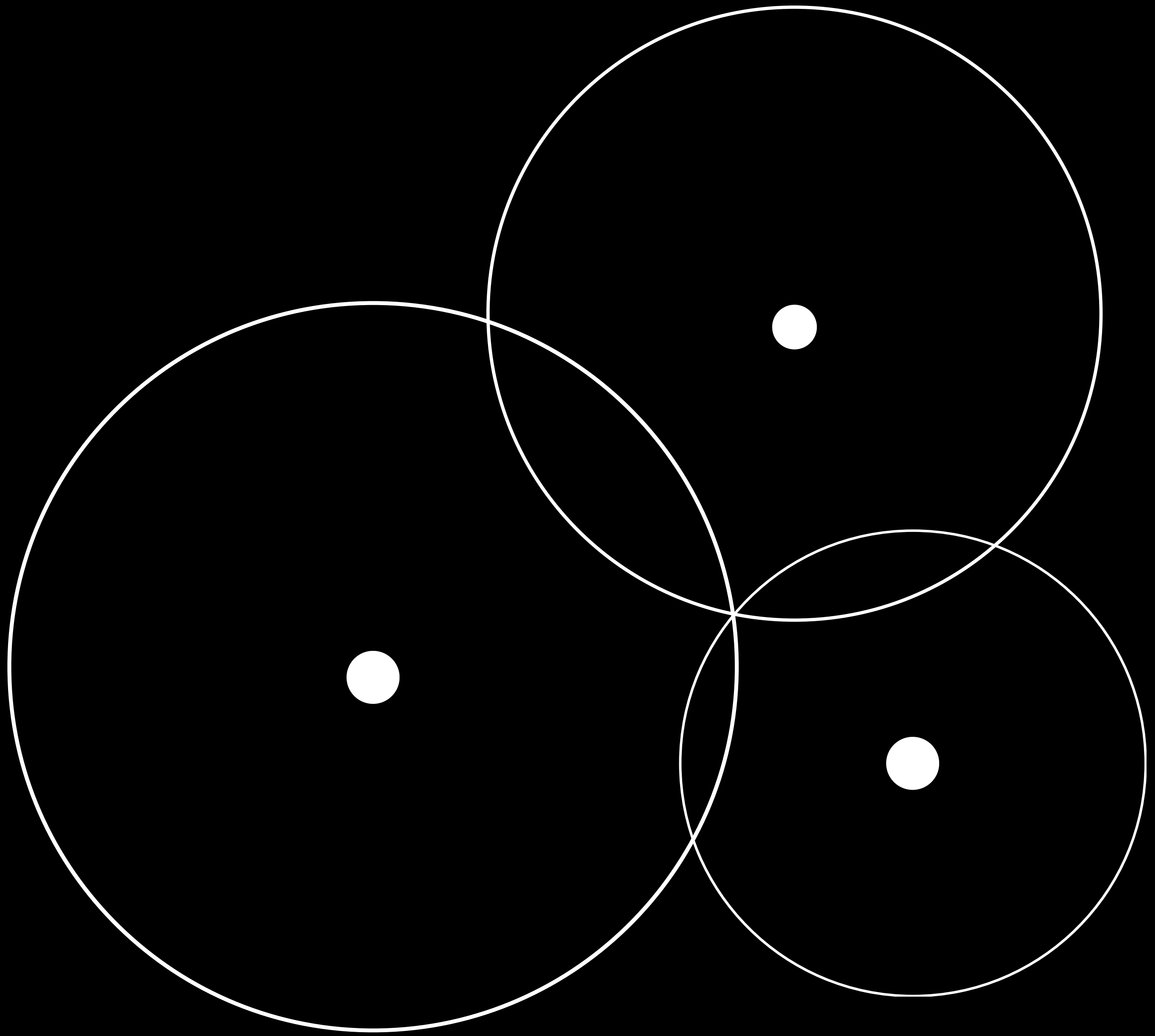


State Transition Diagram



HOW DO WE FIND POSITION

```
% Ensure input vectors are column vectors
towerX = towerX(:);
towerY = towerY(:);
distance = distance(:);

% -----
errorFu                                        ).^2);
initial
estimat

% Compu
residua                                        ) - distance;
sigma =
CEP = 0

% -----
x1 = to
x2 = to

d = sqr

if d > (r1 + r2) || d < abs(r1 - r2)
    error('No valid intersection between the first two towers.');
end

a = (r1^2 - r2^2 + d^2) / (2 * d);
```



TRILATERATION

where the 3 circles intersect tells us position of the transmitter

LEAST SQUARES ESTIMATION ALGORITHM

Why we use it?

- Real-world data is noisy – receiver circles rarely intersect perfectly.
- We need a method to estimate the best possible position using all measurements.
- Least squares helps minimize the total error between measured and computed distances.

How it works?

- Input: known receiver positions + distances from time-of-flight

.

- Compute: the position that minimizes the squared difference between:
  - Measured distance
  - Distance computed from a guessed position

ETHERNET CONNECTION VS WIRELESS

Timing & Reliability

- Our system depends on precise time-of-flight (ToF) measurements.
- These measurements are used to calculate distance
- Therefore, even small delays or packet losses over wireless can introduce significant errors.

Data Transmission

- Low latency
- No interference from other devices
- This is critical in an indoor lab environment, where there exists potential RF noise.

ULTRASOUND VS VISION-BASED SYSTEMS

Implementation & Cost

- The system uses low-cost HC-SR04 ultrasonic sensors
- Open-source microcontrollers like Arduino.
- This keeps the system affordable, modular, and easily replicable, especially in educational settings.

Technical Benefits

- It offers high positional accuracy in smaller indoor ranges.
- It’s immune to lighting conditions, unlike vision-based systems.

TRIANGULATION VS TRILATERATION

Triangulation

- Determines location using measured angles from known reference points.
- Requires specialized angle sensors (e.g., cameras or directional antennas).
- Often used in vision-based or RF angle-of-arrival systems.

Trilateration

- Calculates position using measured distances from three or more known points.
- Each distance forms a circle around a receiver.
- Requires only basic distance sensors (HC-SR04), making it low-cost and robust.

SYNCHRONIZATION OF RADIO MODULES

Strategy

- The Host PC sends a trigger signal to:
- The Transmitter Arduino (on the tractor)
- The Receiver Arduino (connected to the 6 fixed ultrasonic receivers)
- This ensures that both transmitting and receiving subsystems are triggered simultaneously.

Validation

- An oscilloscope was used to analyze timing between transmitted and received trigger signals.
- Echo pins on all six receivers went high exactly when the trigger was received.
- The ultrasonic pulses from the transmitter were emitted immediately after the synchronized trigger.