HO CHI MINH CITY UNIVERSITY OF TECHNOLOGY
FACULTY OF COMPUTER SCIENCE AND ENGINEERING

IMPLEMENTATION OF UWB-BASED INDOOR LOCALIZATION SOLUTION

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CAPSTONE PROJECT

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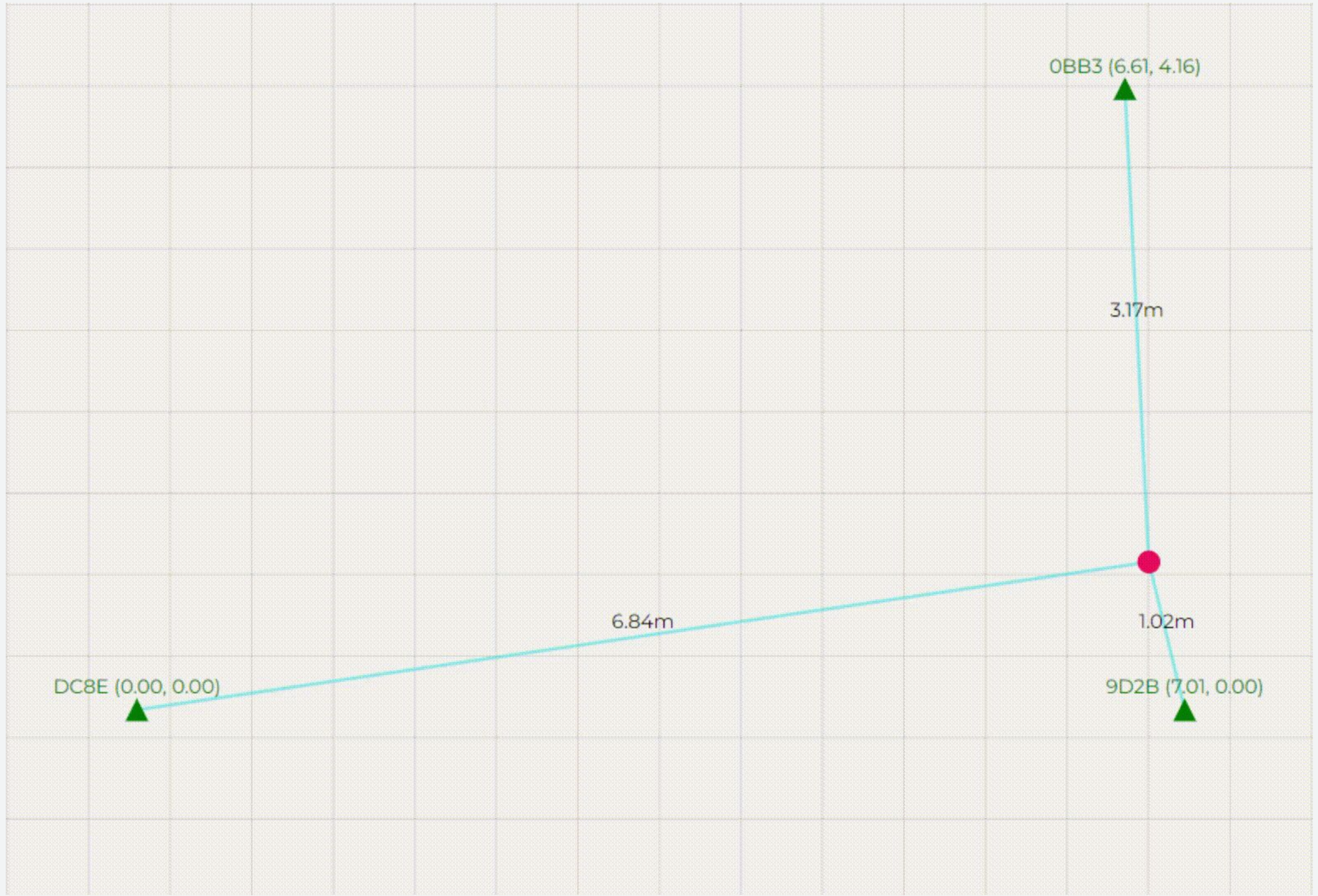
INTRODUCTION

ABSTRACT

Ultra-Wideband (UWB) technology is an **advanced radio technology** known for its ability to provide **precise location data**. An indoor localization solution based on UWB can **track the position** of objects or people within a building **with high accuracy**. This project aims to **design, develop, and implement** a UWB-based indoor localization system.



PROJECT OBJECTIVES

Phase 1
(Computer Engineering Project)

Setting **goals and requirements**. Researching **background knowledge** related to indoor localization technologies and algorithms.

Implementing and comparing those techniques and algorithms to choose the one that fits our requirements.

Processing the **database**, developing **software** to handle UWB data, and **visualizing** the position estimates.

Testing and validating the system based on requirements.

Phase 2
(Capstone Project)

PROJECT REQUIREMENTS

Accuracy: The system is expected to achieve meter-level accuracy, with an **error margin of less than 0.3 meters**, even in non-line-of-sight (NLOS) environments.

Coverage Area: **The simplest setup** of the system could cover an indoor **space of up to 54 square meters** while maintaining an error margin below 0.3 meters.

Display latency: The tag data must be displayed on the application within **6 seconds** after the tag moves.

User-Friendly Application: Develop an **easy-to-use** app that effectively visualizes localization data within **3 steps.**

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BACKGROUND KNOWLEDGE

INDOOR LOCALIZATION

<table>
<tr><td>TECHNOLOGIES</td><td colspan="2">WI-FI</td><td>BLUETOOTH</td><td colspan="2">RFID</td><td>UWB</td></tr>
<tr><td>MEASUREMENT TECHNIQUES</td><td colspan="2">Angle-based methods</td><td colspan="3">Distance-based methods</td><td>Fingerprinting-based method</td></tr>
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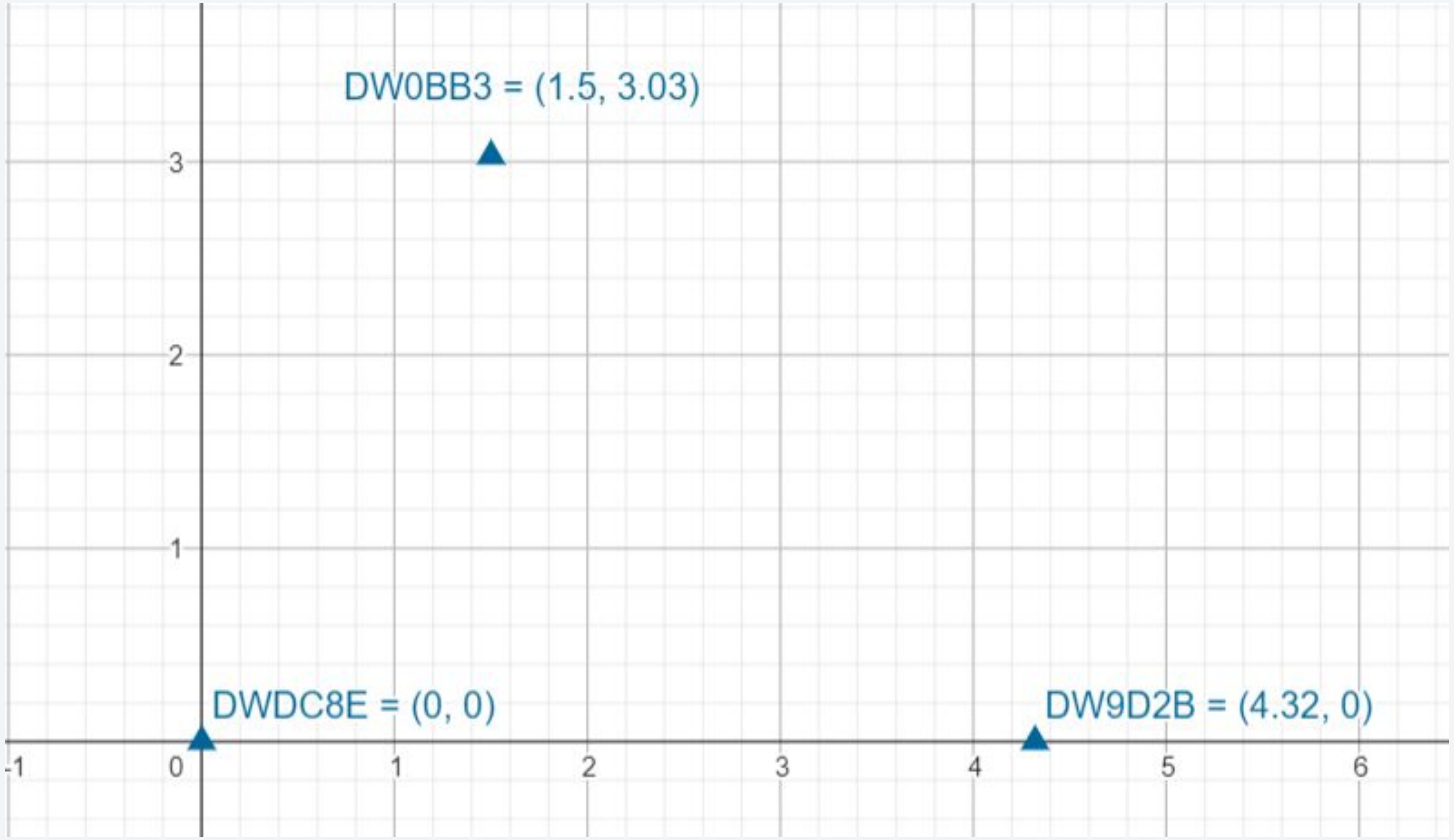
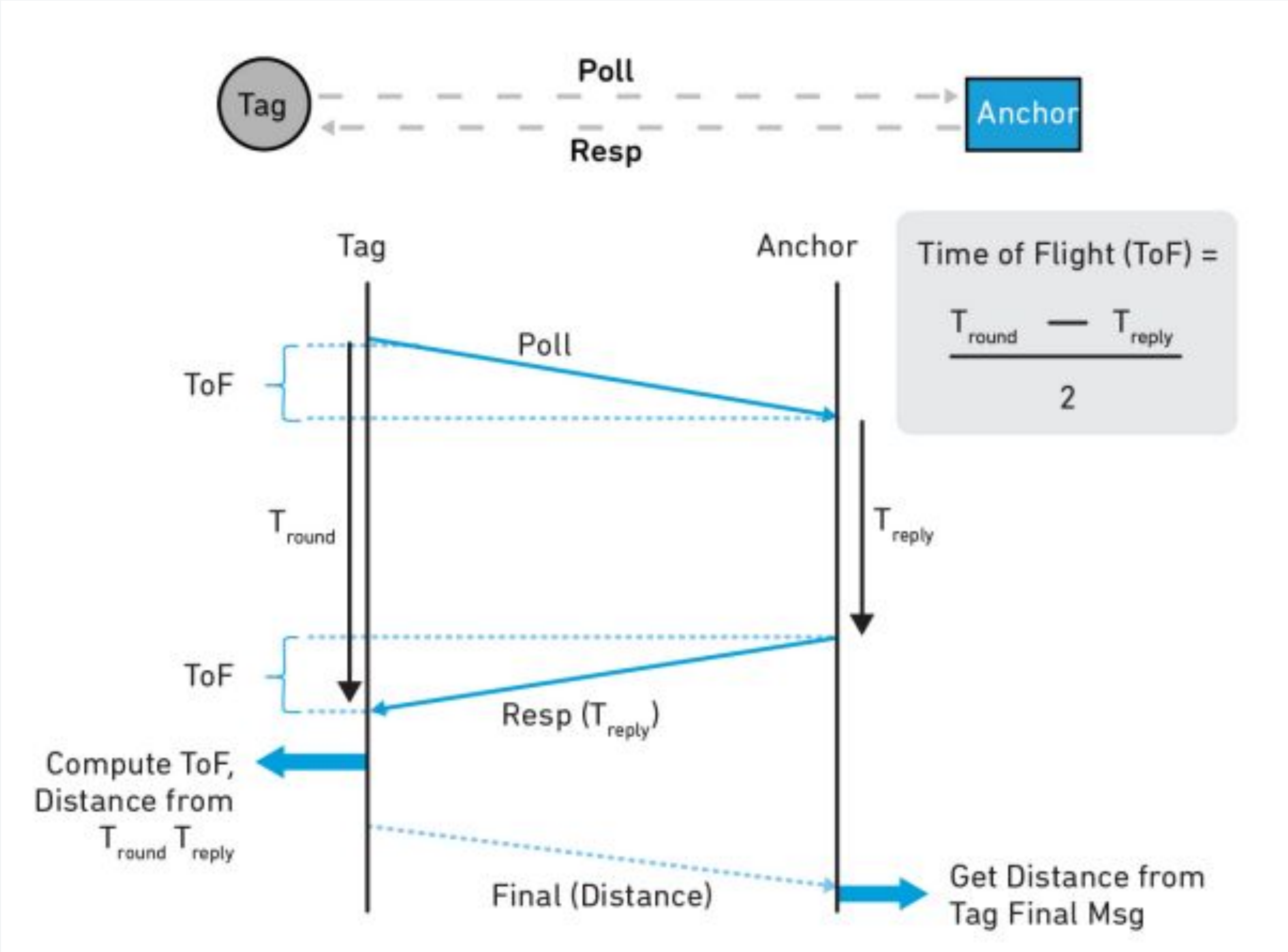


Local coordinate system: the process involves establishing a local coordinate system for a UWB system, determining the origin and orientation, assigning coordinates to anchor devices, then installing them in designated locations, and assigning unique identifiers to each UWB anchor device.

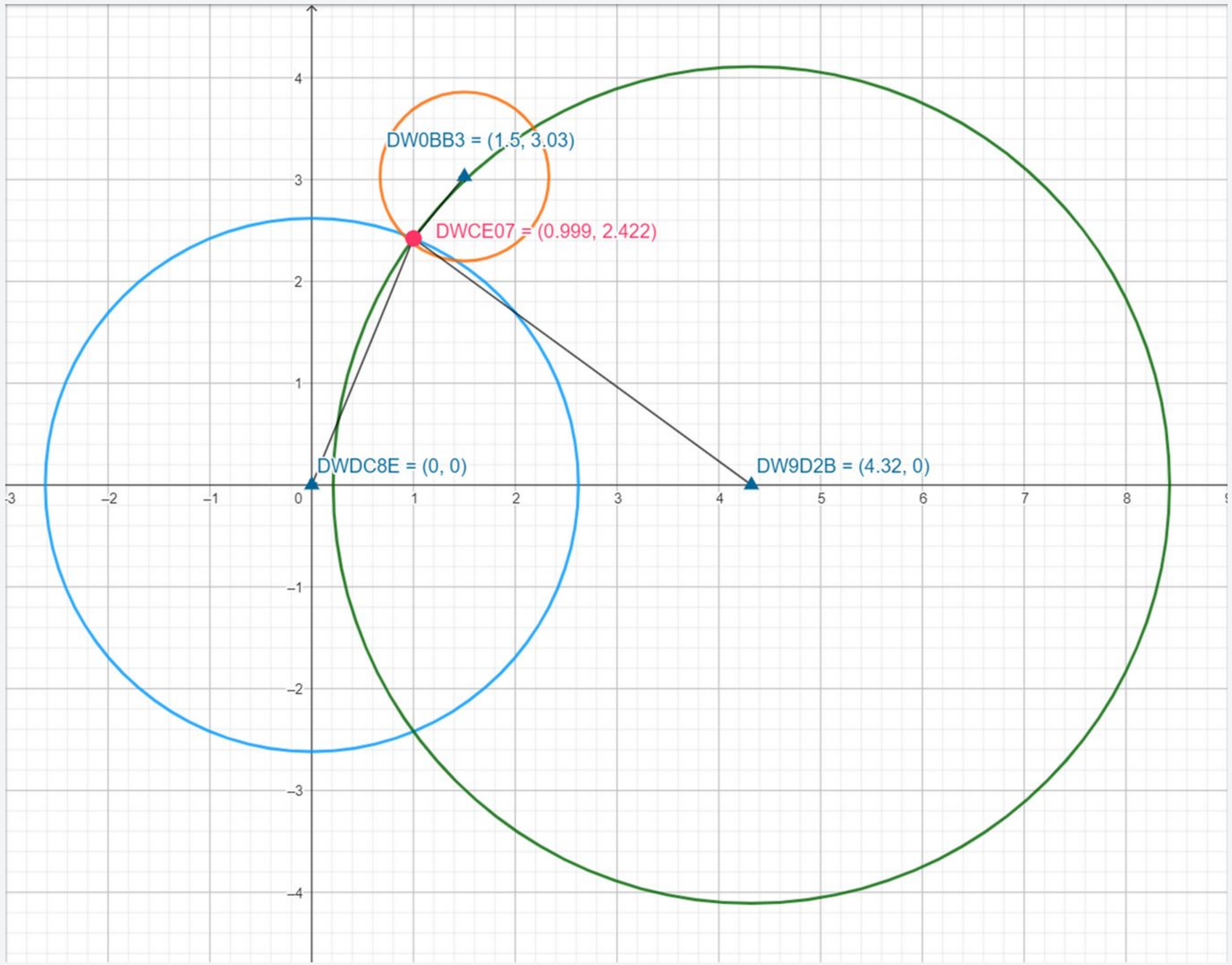


$$Distance = Time\ of\ Flight\ \times Speed\ of\ Light$$

Symmetric Double-Sided Two-Way Ranging: The initiator sends a "poll" frame, after which it waits for a "response" message from the responder to complete the exchange. The response message contains the remote responder's time-stamps of poll reception, and response transmission. Using these time-stamps along with the local time-stamps, calculates the ToF, then calculates the distances.

Implement Trilateration:

$$(x - x_1)^2 + (y - y_1)^2 = {d_1}^2$$
$$(x - x_2)^2 + (y - y_2)^2 = {d_2}^2$$
$$(x - x_3)^2 + (y - y_3)^2 = {d_3}^2$$



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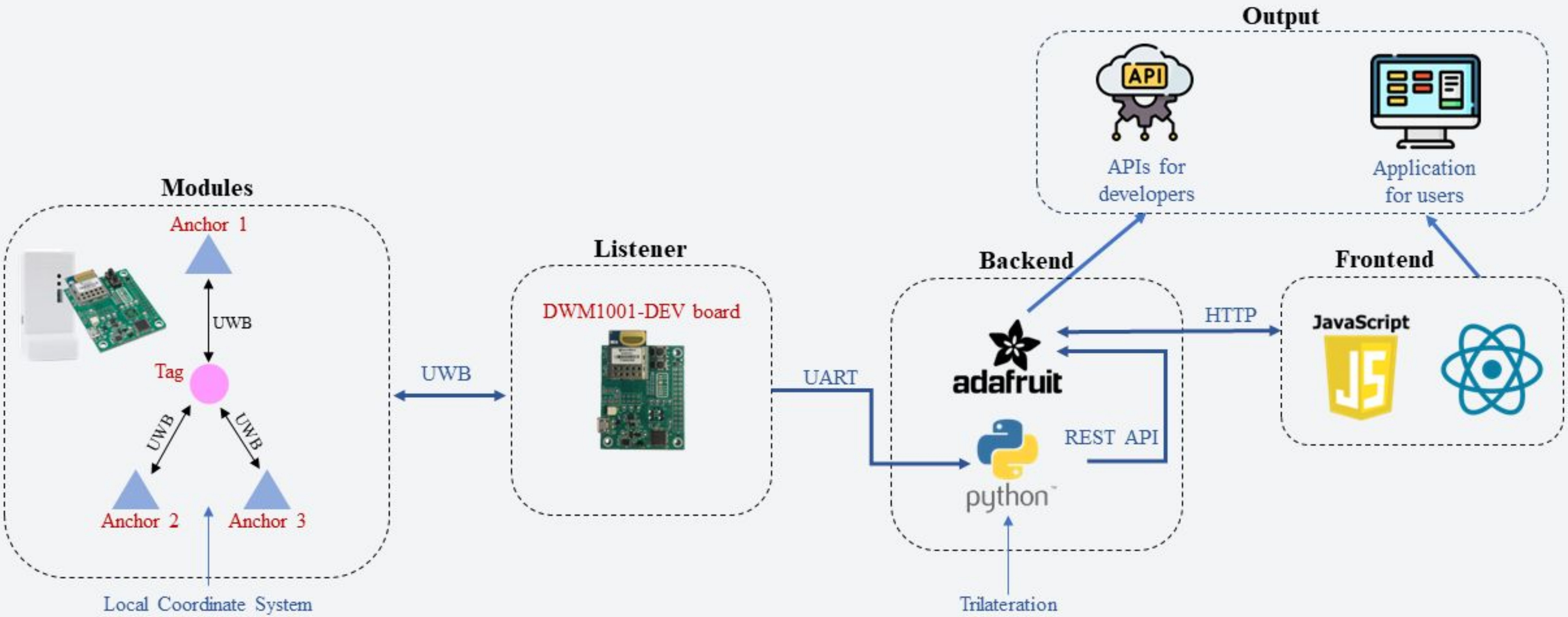
SYSTEM ARCHITECTURE AND IMPLEMENTATION

SYSTEM ARCHITECTURE

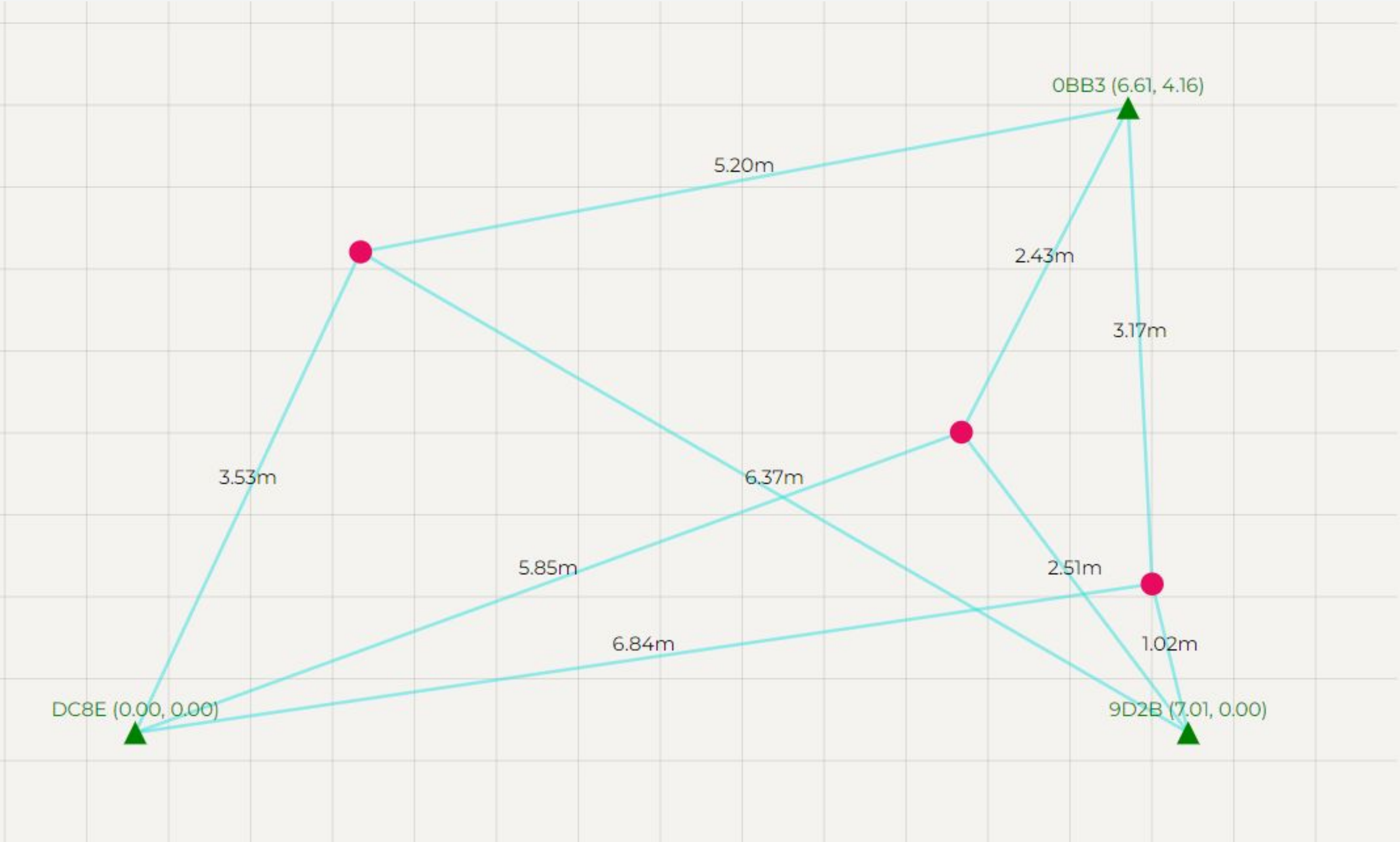


DEMONSTRATION VIDEO OF THE APPLICATION

FOR DEVELOPERS

Guiding robot in National Museum of Korea

Source: YONHAP NEWS Agency



Grid map for tracking multiple targets

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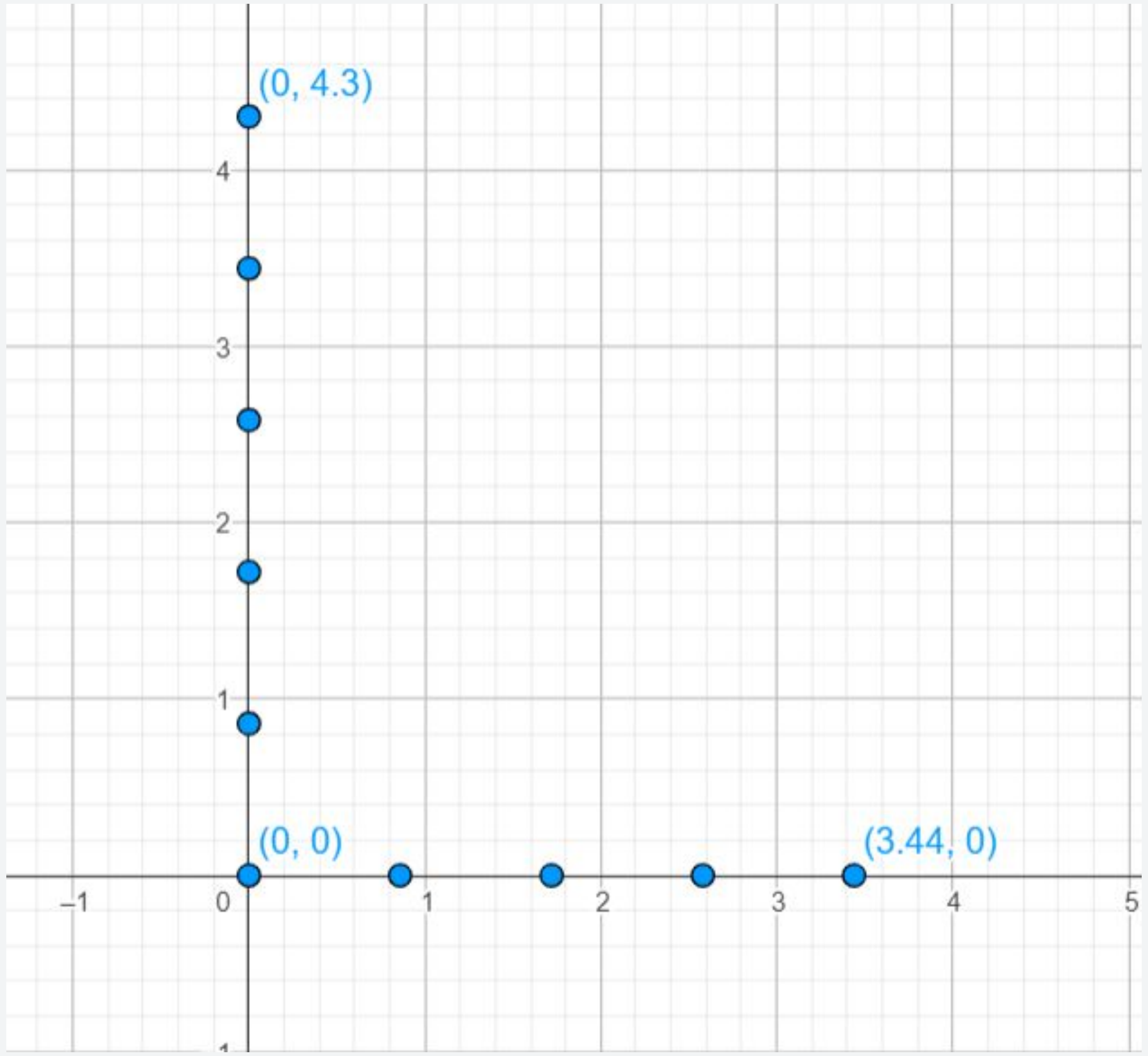
EXPERIMENTS AND EVALUATE

ACCURACY REQUIREMENT

The system is expected to achieve meter-level accuracy, with an error margin of **less than 0.3 meters**, even in non-line-of-sight (NLOS) environments.

EXPERIMENT FOR ACCURACY REQUIREMENT

- **Test Setup:**
  - Room size: 4.3 x 4.5 meters
  - 10 fixed points on a coordinate grid
- **Data Collection:**
  - 10 measurements per point
  - Total: 100 measurements per test
- **Testing Environments:**
  - One test in Line-of-Sight (LOS) environment
  - One test in Non-Line-of-Sight (NLOS) environment
- **Evaluation Methods:**
  - Calculate Euclidean distance for each measurement
  - Compute mean error
  - Determine standard deviation



EXPERIMENT FOR ACCURACY REQUIREMENT

Results

	LOS
Testing points (points)	100
Min Error (m)	0.0335
Max Error (m)	0.5093
Mean Error (m)	0.2565
Standard Deviation (m)	0.2371

	NLOS
Testing points (points)	100
Min Error (m)	0.0451
Max Error (m)	0.5802
Mean Error (m)	0.2843
Standard Deviation (m)	0.2744

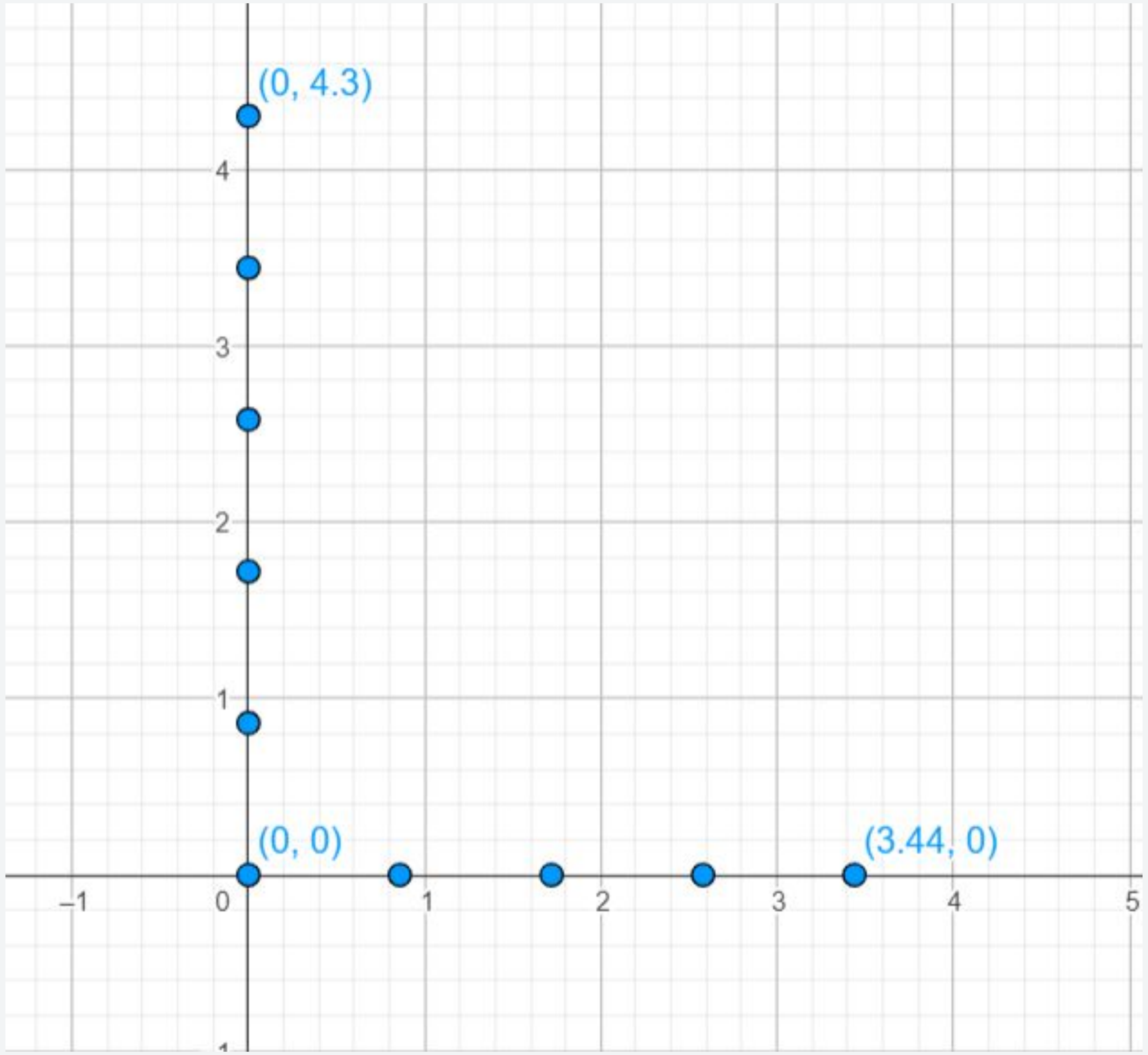
➥ **System consistently achieves high precision with errors well under the required limit.**

COVERAGE AREA REQUIREMENT

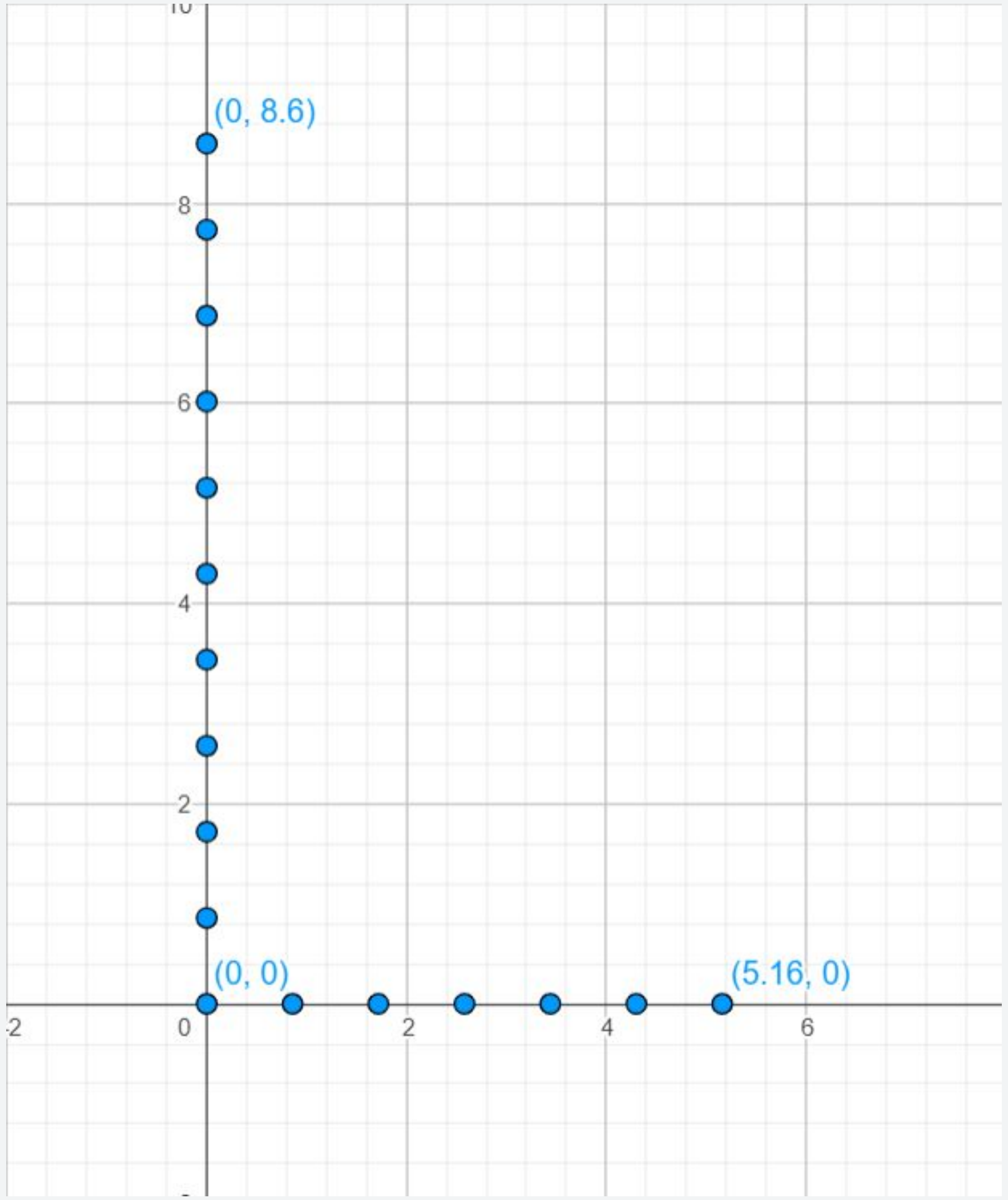
The simplest setup of the system could cover an indoor space of **up to 54 square meters** while maintaining an error margin below 0.3 meters.

EXPERIMENT FOR COVERAGE AREA REQUIREMENT

Room A: 4.3 x 4.5 meters (approximately 19.35 square meters)



Room B: 6.0 x 9.0 meters (approximately 54 square meters)



EXPERIMENT FOR ACCURACY REQUIREMENT

Results

Room A	3 anchors setup	4 anchors setup
Testing points (points)	170	170
Min Error (m)	0.0324	0.0317
Max Error (m)	0.5054	0.5108
Mean Error (m)	0.2618	0.2336
Standard Deviation (m)	0.2402	0.2195

Room B	3 anchors setup	4 anchors setup
Testing points (points)	170	170
Min Error (m)	0.0318	0.0295
Max Error (m)	0.6037	0.5760
Mean Error (m)	0.2844	0.2613
Standard Deviation (m)	0.2748	0.2496

➥ **The simplest setup using 3 anchors continues to deliver good performance in spaces up to 54 sqm.**

DISPLAY LATENCY REQUIREMENT

The tag data must be displayed on the application within **6 seconds** after the tag moves.

EXPERIMENT FOR DISPLAY LATENCY REQUIREMENT

- **Reason for display latency within 6 seconds:**
  - Publish Data Delay: 2 seconds to transmit data to Adafruit.io.
  - Fetch Data Delay: 1 second to retrieve data from Adafruit.io.
  - System Processing Time: Total 3 seconds, doubled for worst-case scenario.
- **Experimental Setup:**
  - Location: 4.3 x 4.5 meter room.
  - Configuration: 3 anchors and 1 tag.
  - Procedure: Track real-time tag movement and application display timing.
  - Repetitions: Conducted 100 times for data robustness.
- **Methodology for Results:**
  - Record Timing: Note times of tag movement and application display per test.
  - Calculate Time Delays: Determine delay between actual movement and display.
  - Compute Mean Delay: Assess if display is within 6 seconds on average.

EXPERIMENT FOR DISPLAY LATENCY REQUIREMENT

Results

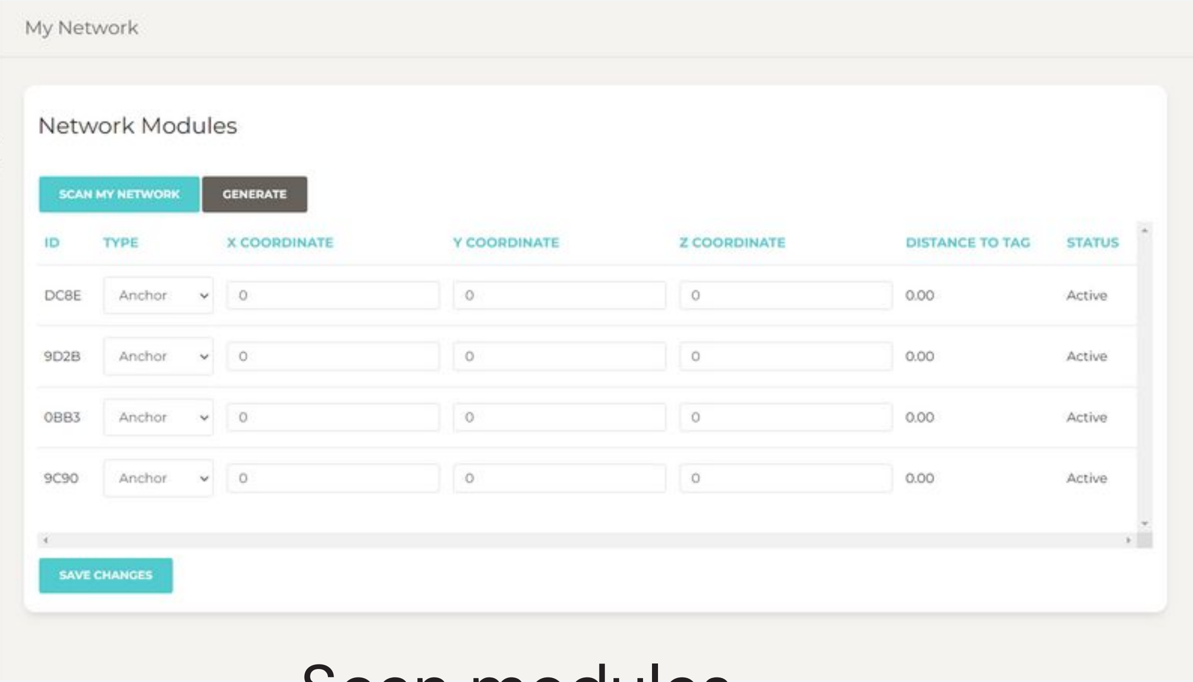
Number of tests (tests)	100
Min Time Delay (s)	2.20
Max Time Delay (s)	8.10
Mean Time Delay (s)	4.92
Standard Deviation (m)	3.20

- **Challenges:**
  - Caused by limitations from using free Adafruit.io service.
- **Conclusion:**
  - Meets requirements despite occasional spikes in delay.
  - Suggests need for improving consistency.

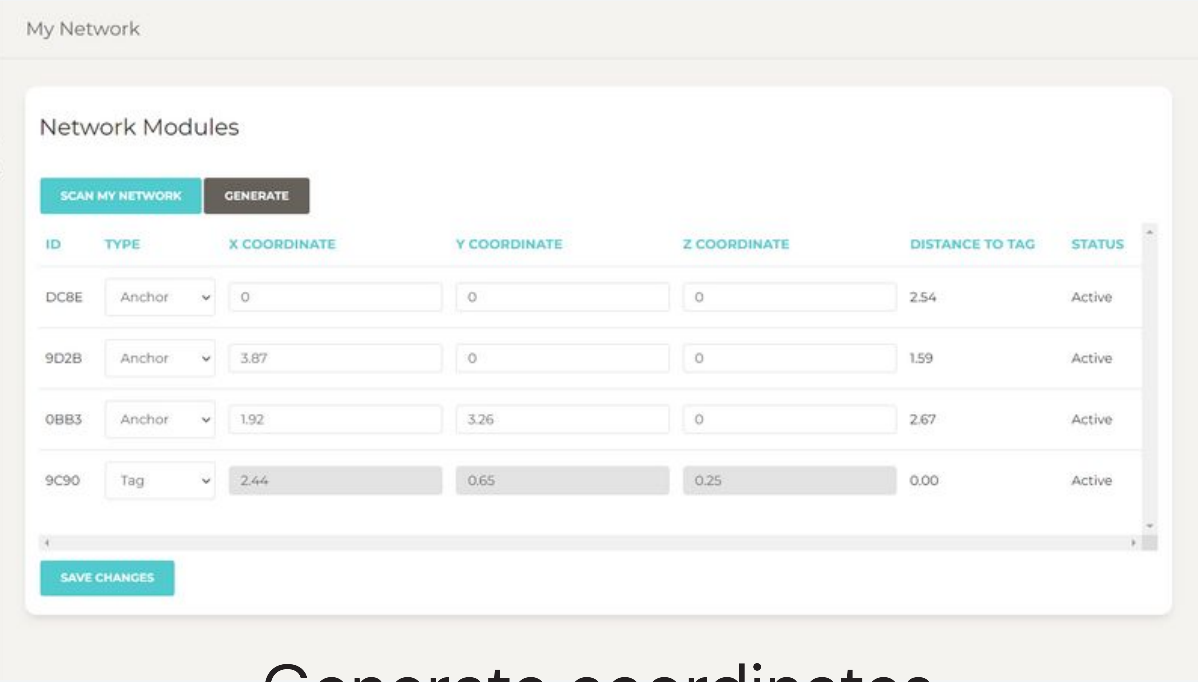
USER-FRIENDLY APPLICATION REQUIREMENT

Develop an easy-to-use app that effectively visualizes localization data within **3 steps.**

Three-Step Visualization Process:



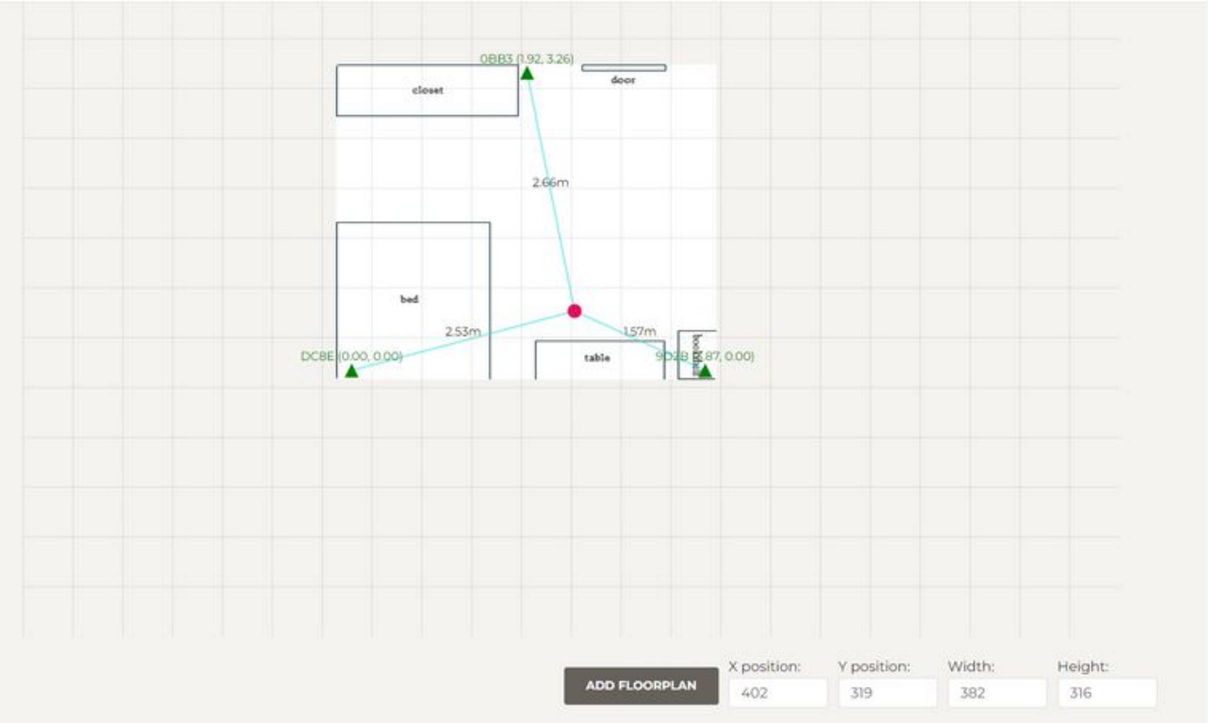
Scan modules



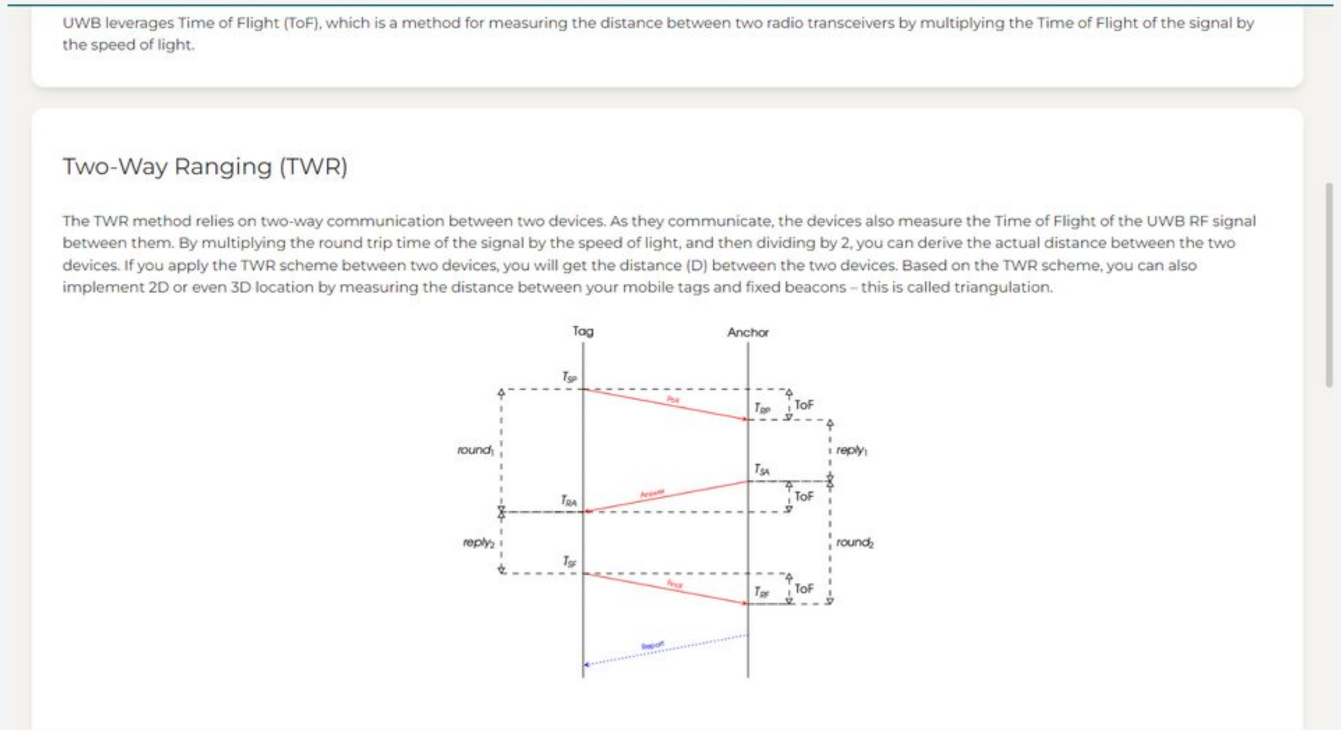
Generate coordinates

View results on a grid map

Enhanced Visualization:



Educational Content:



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CONCLUSION

WHAT WE DID THROUGHOUT THIS PROJECT

Clarified **background knowledge** surrounding UWB-based indoor localization technology

Implemented and compared different methods and algorithms to achieved the expected requirements

Developed the software to handle UWB data, implemented the chosen algorithm, and visualized the position estimates

Tested and validated the system accuracy along with performance under different conditions and scenarios

WHAT WE LEARNED THROUGHOUT THIS PROJECT

Substantial **knowledge** about indoor localization systems.

Data processing and **database usage** for applications.

How to construct **testing scenarios** for a system based on its objectives and requirements.

FUTURE DEVELOPMENT

- **Network Expansion:** Add more anchors and build a gateway (e.g., Raspberry Pi with DWM1001-DEV) for cross-room communication.
- **Hybrid Localization:** Integrate WiFi or Bluetooth with UWB for improved accuracy and reliability.
- **Advanced Visualization:** Upgrade system to display 3D localization results for enhanced environmental understanding.
- **Customized Applications:** Develop features tailored for specific sectors like factories, hospitals, or schools to meet unique needs.

THANK YOU
FOR LISTENING