

ECE Capstone Project Final Report

Project Title	RSSI-based UAV-assisted Radio Frequency Signal Localization Algorithms
Team	[Firuza Barayeva — team leader Tamerlan Sholanov — engineer Balnur Baimagambet — engineer Kassymzhomart Zhamshit — engineer]
Supervisor	RSSI-based UAV-assisted Radio Frequency Signal Localization Algorithms
Course/Term	ENG 400 Capstone Project, [Spring 2026]
Date	[11-04-2026]

Prepared by: [Firuza Barayeva, signature]
[Tamerlan Sholanov, signature]
[Balnur Baimagambet, signature]
[Kassymzhomart Zhamshit, signature]

Reviewed by: [Mohammad Hashmi, signature]

TABLE OF CONTENTS

0. ABET Evidence Map, Final Design Snapshot, and Design Evolution Log	4
1. Executive Summary	7
2. Problem Definition, Stakeholders, Context, and Constraints.....	8
2.1 Problem Definition and Need Statement	8
2.2 Stakeholders	8
2.3 Context and Operating Environment	9
2.4 Constraints and Context Factors.....	9
3. Final Requirements, Acceptance Criteria, and Traceability	11
3.1 Final Requirements Compliance	11
3.2 Requirements Traceability.....	12
3.3 Derived, Interface, Environmental, and Regulatory Requirements	13
4. Engineering Standards, Regulations, and Compliance Evidence	15
5. Concept Generation, Trade-off Study, and Selected Concept.....	17
6. Design Iterations and Decision History.....	25
7. Final System Architecture.....	27
7.1 Experimental Architecture	27
7.2 Data Analysis Architecture	29
8. Detailed Design and Implementation	31
8.1 Hardware design	31
8.2 Software/firmware design	32
9. Verification, Validation and Experimental Results	35
10. Risk Management, Schedule, Budget, and Procurement Outcomes.....	38
10.1 Final Risk Register.....	38
10.2 Milestones Planned vs. Actual	39
10.3 Budget, Procurement, and Substitutions	41
11. Professional Responsibilities and Broader Impacts	43
11.1 Public Health, Safety, and Welfare	43
11.2 Ethical and Professional Responsibilities	43
11.3 Security and Privacy	44
11.4 Accessibility and Usability	44
11.5 Environmental, Economic, Social, Global, and Cultural Factors	44
12. Team Organization, Collaboration, and Individual Contributions	45
13. Use of Prior Course Work and New Knowledge Acquired.....	47
14. Conclusions and Recommendations.....	49
Appendix A. Engineering Standards Evidence	51
Appendix B. Multiple-Constraints Matrix	52

Appendix C. Team Organization and Contributions	53
Appendix D. Design Evidence.....	54
Appendix E. Verification Evidence	58
Appendix F. Project Management Evidence	60

0. ABET Evidence Map, Final Design Snapshot, and Design Evolution Log

This section assists evaluators in identifying the main sections for key objectives and highlighting evidence. All the evidence is provided according to the ABET guidelines and recommendations.

Table 0-A. Report Evidence Guide.

ABET item / SO	What must be demonstrated	Primary report section	Supporting appendix / evidence ID
SO1	Identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	Section 2, Section 5, Section 8	Appendix D Appendix E Section 7
SO2	Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	Section 2 Section 3 Section 4 Section 11	Appendix B
SO3	Communicate effectively with a range of audiences	Section 1 Section 2 Section 14	All project-related presentations, posters, and reports
SO4	Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	Section 11	Appendix A Section 10
SO5	Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	Section 12	Appendix C Tables 12
SO6	Develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.	Section 3 Section 9	Appendix E Table 9-A
SO7	Acquire and apply new knowledge as needed, using appropriate learning strategies.	Section 8 Section 13	Appendix D
<i>Criterion 5 design evidence</i>	The culminating design shows standards, multiple constraints, iteration, and use of prior course work.	Section 2 Section 4 Section 5	Appendix A, B

ABET item / SO	What must be demonstrated	Primary report section	Supporting appendix / evidence ID
		Section 6 Section 7 Section 13	

Table 0-B. Final Design Snapshot.

Field	Final value/summary
Final prototype/revision	Final design consists of a Raspberry Pi 4 + Wi-Fi adapter and a power bank in a 3D-printed casing. The setup is mounted on the UAV.
Main need addressed	Localization of a ground beacon transmitter.
Requirements met	All main requirements met (REQ 1-5), which were: ≥ 20 measurements per anchor point; Sampling Frequency = 4.65 Hz; An improvement after a pre-processing $\geq 70\%$ of points within error threshold; . Localization error $\leq 15\%$ of the diagonal
Primary standards applied	ITU Radio Regulations Chapter 2 Article 5: Frequency allocations; Order No. 706 of the Acting Minister of Industry and Infrastructure Development of the RK; UN/DOT 38.3: Lithium metal and lithium ion batteries; FCC Part 15 Subpart C ISO/IEC 27001:2013
Key constraints satisfied	BOM < 100 MCI (actual expenditure 46 480 KZT = 11 MCI) Localisation error <1 meter (actual achieved: 0.7 meters)
Most important trade-off	Estimation accuracy and reliability are criteria that weigh more than others in our trade-off matrix
Overall result	The project team successfully demonstrated and accomplished the outlined objectives: estimated the position of a transmitter using multilateration RSSI data at different anchor points. Data is gathered via a UAV. Anchor points are predetermined and marked.

Table 0-C. Design Evolution Log.

Iteration ID	What changed	Why it changed	Evidence that triggered the change	Impact on performance / cost / schedule / risk	Date
ITE-1	A Wi-Fi adapter replaced the SDR	Simpler and cost effective hardware	Initial set up was evaluated as more complex and expensive	Cost reduction, more flexibility	Nov 2025
ITE-2	Change of experimental testing field	The initial bench test in previous environments showed inconsistencies	Initial two tests showed positioning error higher than a threshold values	More reliable and improved accuracy	March 2026
ITE-3	Localisation algorithm changed to CHLM	Account for experiment conditions	Previous algorithm was inconsistent and slow	Increased precision	Feb 2026
ITE-4	Trying different movement pathways	Trial and error method to identify optimal trajectory	Initial test showed a square path with less error	The variation in RSSI data increased, leading to more evidential conclusions	March 2026
ITE-5	Change of router equipment	Previous router showed lower effective range	Initial router was designed to be effective at radius of <5 meters	The router (beacon transmitter) showed increased effective range of >5 meters	Feb 2026
ITE-6	Change of receiver antenna	Initial antenna was damaged beyond repair	Risk event: UAV uncontrolled flight damaged the antenna	New antenna proposed improved coverage of receiver, improving effective radius of the experiment	March 2026
ITE-8	Change of the RSSI logging software utility	More effective logging of the RSSI values	Slow pace of RSSI logging, leading to the increased error rate	RSSI logging became more precise and faster	March 2026

1. Executive Summary

- Background and Motivation

Unmanned Aerial Vehicles (UAVs) are widely employed in wireless networks due to their mobility, flexibility, and opportunities for wide-area coverage. One of the major challenges in UAV-assisted communication is the localization of signal sources. Our main goal is to estimate the position of a transmitter using multilateration RSSI data at different anchor points. Determining the position of Radio Frequency (RF) emitters has various potential applications. For example, in rescue missions, victims can be located by their phone signal [1, 2]. Secondly, UAVs can be used to detect jammers and unauthorized transmitters [3, 4].

- Problem Statement and Need

Achieving high localization accuracy is challenging due to interference, noise, shadowing, and multipath fading [3]. Moreover, any UAV application should consider size, weight, and power (SWaP) constraints; therefore, fast and computationally simple algorithms are more practical [5].

- Final Design Solution

In this project, the UAV follows a predefined trajectory while recording RSSI measurements from a ground transmitter, a Wi-Fi router. As the vehicle lands, gathered data is used to estimate the location of the transmitter. First, we will simulate a UAV flight to design and test different localization techniques. Then, we will choose one of the methods and validate it using data from real experiments. Experiments are conducted in a controlled indoor environment. The flow is outlined as follows:

- Final Performance Achieved

Final Performance Achieved

- A UAV equipped with a Raspberry Pi logging system and the receiver is prepared
- A UAV is piloted over the pre-defined trajectory
- The gathered data is extracted as input to the algorithm
- Anchor point selection is performed
- The transmitter location was determined based on trilateration using anchor points

- Requirements met / Partially met / Unmet

Requirements met:

- The system shall collect RSSI samples at predefined UAV trajectory points.
- Hardware should receive wifi packages with a minimum frequency of 4 Hz
- The algorithm should implement data processing to increase efficiency
- The system shall accurately convert RSSI to distance
- The system shall estimate the location of a transmitter based on ground trial

Requirements unmet:

- The system shall estimate the location of a transmitter based on aerial trial

- Main Limitation and Recommended Next Step

The main limitation in this experiment is the accuracy of the data. As it was said in the previous parts, due to the interference, noise, shadowing, multipath fading, and most importantly due to the limitations with very accurate technologies, the experiment outcome was far from the desired ones. Consequently, it is recommended to find more accurate technology and get rid of noise by introducing software-based noise filtering.

2. Problem Definition, Stakeholders, Context, and Constraints

2.1 Problem Definition and Need Statement

Accurate localization of a ground-based transmitter using a mobile UAV equipped with a receiver is a significant engineering challenge. Search and rescue teams, law enforcement, and other first-responder operations often need rapid coverage of large areas with limited ground-level access. This project aims to meet this need by designing, building, and testing a UAV-based localisation algorithm based on RSSI measurements. A lightweight UAV, carrying a receiver module, follows a predefined path over the target area, records RSSI values at certain positions, and converts them into distance estimates. This project involves not only selecting appropriate hardware but also exploring different methods.

2.2 Stakeholders

Within the scope of this project, the following stakeholders were identified:

Table 2-A. Stakeholder Analysis.

Stakeholder	Role/Interest	Needs/Success criteria	How engaged (meetings/inputs)	Impact of the project
Project team	Developers	Graduation from university	Direct engagement	Academic success
Rescue service	Potential users	Timely and accurate location prediction Reproducibility	Acts as an indirect test for consumers	Alternative rescue service tool
Law enforcement	Potential users	Timely and accurate location prediction Robustness of setup	Indirect consumers	Passive positioning tool
City government	Potential users	Timely and accurate location prediction Shows longevity	Indirect consumers	Integrating element for the citywide Internet of Things

Project supervisor	Management	Project meets minimal criteria	Weekly meetings with progress reporting	Successful engagement with students
--------------------	------------	--------------------------------	---	-------------------------------------

2.3 Context and Operating Environment

This project was developed in response to growing interest in wireless sensing using UAVs, which has become more popular than conventional search antennas due to their relatively low cost, rapid deployment, and ease of use. This technology allows for rapid scanning of a given area for a signal and its detection, while a user using wireless signal transmission can detect the signal at a great distance from the source. However, most academic research currently focuses on developing and improving the technology's performance due to accuracy limitations. This accuracy limitation happens mostly due to noise, interference, shadowing, and multipath fading. This project's main benefit is for the development of comparably low-cost and lightweight UAV drones that can be constructed in large quantities, yet still be efficient enough in detection. While many academic works concentrate on accuracy enhancement, our main goal is to make the system cost-efficient. In terms of equipment, the project requires minimal hardware. We just need an operable light drone, a signal receiver, a small transmitter, and a small signal analyzer on the drone, which will analyze the received signal and send it to the user. With this setup, there is no need for excessive investments for this project. Hence, the project complies with the institutional guidelines, safety standards, and academic requirements. Regarding the regulatory context, UAV flights are conducted in compliance with the regulations. Experiments were planned indoors, hence no requirement to receive an aviation certificate.

2.4 Constraints and Context Factors

Table 2-B. Constraints Matrix.

Constraint category	Metric / target	Final estimate or measurement	Gap / residual risk	Owner	Evidence / next action
Cost	BOM <100 MCI	Current BOM = 27-30 MCI	-	Firuza	EV-201
Power	UAV completes full trajectory	No estimation is possible at the moment	The battery volume is not enough to	Zhomart	Complete multiple test flights with

			complete the flight		different durations
Safety	Completed safety checklist/no flight accidents allowed	Keep flights <25m in altitude, indoors, with minimal #of people around	The flight test could happen in a crowded, dense environment	Balnur	Choose a fitting test facility
Test Performance	Minimal localization error	<5% of corrupted data	The TX-RX connection quality is affected by noise	Tamerlan	Improve the architecture of RSSI localization hardware
Schedule	The Gantt Chart is provided in the report	Hardware delivery is delayed, but in general, we stick to the schedule	The risk of not completing the project in time	Firuz	Introduce team management techniques, allocate tasks between team members

3. Final Requirements, Acceptance Criteria, and Traceability

3.1 Final Requirements Compliance

Table 3-A. Final Requirements Compliance Matrix.

Req. ID	Requirement statement	Source	Verification method	Target threshold	Measured result	Verdict	Evidence ID
REQ-1	The system shall collect RSSI samples at predefined UAV trajectory points.	Data collection	Functional test + log inspection	At least one RSSI sample per waypoint recorded	All anchor points are logged during the experiment	PASS	EV-301
REQ-2	Hardware should receive wifi packages with a minimum frequency of 4 Hz	Hardware design	Continuous packet capture testing	More than >1 packet per second recorded	Average sampling frequency is 4.65 Hz	PASS	EV-302
REQ-3	The algorithm should implement data processing to increase efficiency	Algorithm	Analysis: comparison of raw data with filtered data.	100% of data filtered, 2-3% of errors removed	Outlier removals	PASS	EV-303
REQ-4	The system shall accurately convert RSSI to distance	Algorithm / Calculation	Comparison between derived and experimental data	70% of samples should be accurate	Analysis in section 9	PASS	EV-304
REQ-5	The system shall estimate the location of a transmitter	Algorithm	Test with the known location of a transmitter.	The predicted location shall lie within one grid cell of the	Predicted location is within 1 grid cell + predicted location error is	PASS	EV-305

	based on ground trial			true transmitter position & Localization error should be less than 15% of the testing area diagonal	15% of the diagonal		
REQ-6	The system shall estimate the location of a transmitter based on aerial trial	Algorithm	Test with the known location of a transmitter		Predicted location is not within 1 grid cell + error > 15% of the diagonal	NOT PASS	EV-306

3.2 Requirements Traceability

Table 3-B. Requirements Traceability Matrix.

Stakeholder need	Requirement(s)	Constraint(s)	Standard clause(s)	Design feature(s)	Test ID(s)	Result section
Real-life applicability and scalability	REQ-6	Continuous movement; outdoor applicability; real-time data collection	-	Real-time updates in algorithm	UAV test	9
Locate the unknown TX location	REQ-1, REQ-3	Error < 5%	-	Manual flight control	T1 and T5	9
Wireless signal	REQ-2	Wi-Fi 4/5/6 2.4/5 GHz fixed band	STRD-1 STRD-4	Wi-Fi adapter - AWUS036ACS	T2	9
Accurate conversion of RSSI to distance	REQ-3	Specific path-loss exponent, base value	-	Data calibration	T3	9
Robust estimations with little impact from the environment	REQ-4	Processing time < 1 sec	-	RSSI < -70dbm	T4	9

Stakeholder need	Requirement (s)	Constraint(s)	Standard clause(s)	Design feature(s)	Test ID(s)	Result section
Structured data for an algorithm	REQ-1	-	ISO 8601	Data logs	T2	9
Safe and legal UAV control	Safety check	Indoor environment	-	Preflight checklist, indoor experiment zone selection	Preflight inspection	9

3.3 Derived, Interface, Environmental, and Regulatory Requirements

- **Derived requirement**

- a . The errors in data points shall be removed before distance estimation.
 - Values lower than -70 dBm were removed. Evidentially, good Wi-Fi connectivity values should be in between -40 and -30 dBm. The values higher than -70 dBm occurred because of uncontrollable concepts like loss of line of sight and multipath propagation. RSSI values are the most important concept during data acquisition stage, hence, it is sensitive to the outliers and they must be removed before data analysis.
- b . The drone movement shall be synchronized with the logging system manually
 - It is important to map drone position to readings. Multiple ways of doing it were discussed in section 5.
- c . SWaP constrains
 - Size: receiver should be relatively smaller than the drone
 - Weight: should be low enough so drone can take flight
 - Power: Taking into account the need for multiple trials, drone flight time should be limited to 5 minutes to not spend too much power
 - Power: The localization algorithm should be simple and non-complex. While in this project, computation is on-the-ground after the flight had happened, the ambition is to have autonomous on-board real-time target estimation. If the algorithm runtime is long, it will waste more energy, creating an inefficient system.

- **Interface requirement**

- a . The input data files created from the experiment shall have the same format.
 - Standardized data format allows straightforward and consistent data analysis. It should also be clear to other people reading the documents.

Worksheet Name	Description	Data Scheme
----------------	-------------	-------------

Title page	All necessary data and experiment information	Project information; date; document layout; experiment field description
Terminal log	Raw data capture from receiver (unprocessed measurements)	timestamp (datetime): packet arrival time (system time); rssi_dbm (float): measured RSSI of received packet
Raw data	Preprocessed dataset with filtered measurements for analysis	timestamp (datetime): packet arrival time rssi_dbm (float): RSSI after filtering / cleaning
Data processing	Aggregated statistics per anchor point / time interval	anchor_timestamp (datetime): local time when anchor point is reached interval_start (datetime): start of interval interval_end (datetime): end of interval mean_rssi (float): average RSSI in interval sample_count (int): number of measurements std_rssi (float): standard deviation of RSSI
Pathloss	Distance to rssi relationship	distance (float): distance between transmitter and receiver rssi (float): average RSSI at given distance
RSSI	Maps anchor points to average rssi	x (float): x-coordinate of an anchor point y (float): y-coordinate of an anchor point rssi (float): average RSSI at a given anchor point
Target	coordinates of a target	x (float): x-coordinate of a target y (float): y-coordinate of a target

- b . Receiver shall translate readings to the laptop.
 - By preliminary seeing the recorded data, some problems are avoided. If the connection is lost and logging doesn't happen, it can be seen through low update rate. If the connection is weak and scattered, it can be seen through lower than usual readings
- **Environmental limit**
 - a . The testing field shall be an indoor open area
- **Regulatory or safety requirement**
 - a . Compliance with flight regulations when working with a UAV
 - b . The experiment flow oversees the UAV's emergency landing capability

4. Engineering Standards, Regulations, and Compliance Evidence

Table 4-A. Standards Application Matrix.

ID	Standard / regulation	Clause used	Why applicable	Design decision affected	Verification / inspection method	Evidence produced	Compliance status
STR D-1	ITU Radio Regulations Chapter 2 Article 5: Frequency allocations	Footnotes 5.138, 5.140, 5.280, and 5.398A: ISM Band Allocation - 2.4 GHz (unlicensed band)	To ensure that Tx remains inside the ISM band - no out-of-band emission	Selection of operating frequency	Analysis of the experiment data (RSSI and attenuation) Review of the connection settings	1) TX calibration screenshot 2) TX configuration settings	☐
STR D-2	Order No. 706 of the Acting Minister of Industry and Infrastructure Development of the Republic of Kazakhstan dated December 31, 2020	“On approval of the Rules for the use of unmanned aerial vehicles in the airspace of the Republic of Kazakhstan.”	Defines where and how flight testing can occur; observer required	Experiment field selection	Inspection of the testing site, non-crowded indoor area with enough space for the UAV flight	1) Supervisor approval 2) Video/photo evidences of testing	☐
STR D-3	UN/DOT 38.3: Lithium metal and lithium ion batteries	Clauses: 38.3.4: Procedure and 38.3.2: Scope	To maintain safety and prevent hazards associated with the improper handling of battery packs	Selection of battery capacity, voltage, and chemical composition	Inspection of charging, temperature, and voltage parameters before the experiment	Lithium battery usage datasheet	☐

STR D-4	FCC Part 15 Subpart C	Section 15.247: Operation within 2.4- 2.4835 GHz band	To ensure that a system operates within a certain frequency and on a limited transmission power	Uplink connection between Tx and Rx must comply with the standard	Review of connection settings, such as frequency, power of transmission	1)Device manual/datasheet. 2)TX config. settings	☐
STR D-5	ISO/IEC 27001:2013	Annex A.10: Cryptographic Controls	To securely store and protect the data	Data storage method selection, encrypted connection between Tx and Rx	Version-control storage and Password implementation on the uplink connection	Wireless device configuration settings	☐

5. Concept Generation, Trade-off Study, and Selected Concept

In this section, we will discuss multiple solutions to engineering challenges

5.1 Multilateration,

5.2 Time - Position synchronization,

5.3 Anchor point selection.

5.1.1 Candidate Concepts - Multilateration

Multilateration is a common localization technique based on measuring the distances between a target and landmarks. When the distance is not known directly and derived through other measurements, the method is called pseudo-range multilateration. In GPS systems, Time Difference of Arrival is common [6]. Another frequently used method is Time of Arrival. For indoor localization, RSSI is often employed [7].

Table 5.1-A. Candidate Concepts.

Concept	Description	Strengths	Weaknesses	References/ evidence
Time Difference of Arrival	Uses time difference of a signal arrival at multiple receivers. Receivers must be synchronized	Widespread method without need to transmitter synchronization	The project has a single mobile receiver, while TDoA operates with multiple receivers.	[6]
Time of Arrival	Uses absolute signal travel time. Receiver must be synchronized with a transmitter	Straightforward method	These methods require highly precise propagation modelling and synchronization, overall perform poorly in indoor conditions and close distance	
RSSI	Derive from propagation model and time of flight	Simple implementation and suited indoor applications	Can suffer from accuracy	[7]

5.1.2 Weighted Trade-off Study

The trade-off study for multilateration is inapplicable.

5.1.3 Selected Concept and Rationale

Research had shown that Time Difference of Arrival and Time of Arrival are not suitable for the given project, therefore, RSSI-based distance estimation was selected.

5.2.1 Candidate Concepts - Time-Position Synchronization

A key challenge in this experiment, and a constraint to full automation or on-board real-time processing, is mapping the receiver measurements to its physical position along the trajectory.

During data collection, a person or UAV carrying the receiver moves along the pre-defined path while logging takes place. This section approaches real-time position tracking possibilities.

Table 5.2-A. Candidate Concepts.

Concept	Description	Strengths	Weaknesses
1. Continuous (no waypoints)	Receiver moves continuously along trajectory at a constant speed	Fast; realistic data collection; no manual recordings	Assumes constant speed → inaccurate mapping; inconsistent data
2. Separate sampling	Measurements are taken independently at each anchor point	High accuracy per point; minimal noise	Not scalable; slow; not automated
3. Hardware-based tracking	Uses sensors (IMU, GPS, vision) to track trajectory and synchronize data	High precision; minimal human error; fully automated	Expensive; complex implementation
4. Trigger-based recording	Manually trigger a measurement at each anchor point during a run	Simple; partially automated	Collects limited samples per point; remote control of receiver is a hardware challenge
5. Walk-and-stop	Receiver stops at each anchor point; timestamps recorded for mapping	Higher data density; improved mapping accuracy	Time-consuming; requires manual input

Table 5.2-B Relationships between metrics and project requirements

Metric	Description	Related Requirement(s)
Sampling density	Number of RSSI samples collected per anchor point	REQ-1
Sampling frequency	Rate at which Wi-Fi packets are received	REQ-2

Experiment duration	Time required to complete one full trajectory - single run duration	SWaP
Hardware complexity	Complexity of additional hardware	SWaP
Automation level	Degree of human involvement required	Real-life applicability and scalability
Data consistency	Stability of RSSI measurements	REQ-1, REQ-4
Scalability	Ability to extend to larger areas or more points	Real-life applicability and scalability
Realism	How closely experiment reflects real-world deployment	Real-life applicability and scalability

Table 5.2-C. Weighted Trade-off Matrix

Criterion	Metric / Target	Weight	1. Continuous (no waypoints)	2. Separate sampling	3. Hardware-based tracking	4. Trigger-based recording	5. Walk-and-stop
Sampling density	1 sample per anchor point = 1, >20 sample per anchor point = 10	0.2	3	10	3	3	10
Sampling frequency	1 sample per second = 1, > 5 sample per second = 10	0.05	10	10	10	3	10
Experiment duration	1-2 minutes = 10, > 4 minutes = 1	0.2	10	1	10	8	8

Hardware complexity	1 - Requires developing and implementing new hardware components 5 - Requires minor additional hardware or integration effort 10 - Requires no additional hardware	0.2	10	10	1	5	10
Automation level	1 - Fully manual 5 - Partial automation with some manual input 10 - Fully automated	0.1	5	1	10	5	3
Scalability	1 - Fast data analysis with fewer than 10 anchor points 5 - Fast data analysis with fewer than 20 anchor points 10 - Fast data analysis with more than 50 anchor points	0.15	3	1	10	5	5
Realism	1 - Ground-based operation with interruptions, no automation, no real-time processing 5 - Partially continuous operation with limited automation 10 - Continuous UAV operation with full automation and real-time processing	0.1	5	1	10	5	3
Final score		1	6.55	5.05	6.8	5.1	7.45

5.2.3 Selected Concept and Rationale
Hardware-based automated location tracking is technically difficult to execute, while manual

recording introduces human error and inaccuracies. The final chosen strategy is to manually record time when the receiver reaches every anchor point. After the experiment, these timestamps are used to associate the recorded RSSI data with corresponding spatial locations – mapping. To improve the accuracy, the receiver stops at every anchor point for 5 seconds – this decreases room for error by allowing more readings at every point, and does not affect timing and scalability of the experiment. This workflow is referred to as ‘walk-and-stop’.

5.3.1 Candidate Concepts - Anchor point selection.

According to literature [5], using all of the available dataset can be undesirable, especially when considering on-board processing and computation complexity constraints.

Different processing methods applied to the same data can lead to different outcomes. The concept is having acquired information from multiple points across the field, developing a math algorithm that will minimize errors and create best results. While more points can seem to result in higher accuracy, in reality it is not necessarily the case. Experimental results show that certain measurements can be biased, and even a single inaccurate point can significantly distort the prediction. For example, in figure (a) prediction is more accurate than (b), although (a) uses only 4 corner points and (b) considers all of the points. This is because cumulative consists of biased points. But since it is hard to indicate

This work aims to develop a universal reliable and accurate localization algorithm. By using the same data in different ways, the result can change.

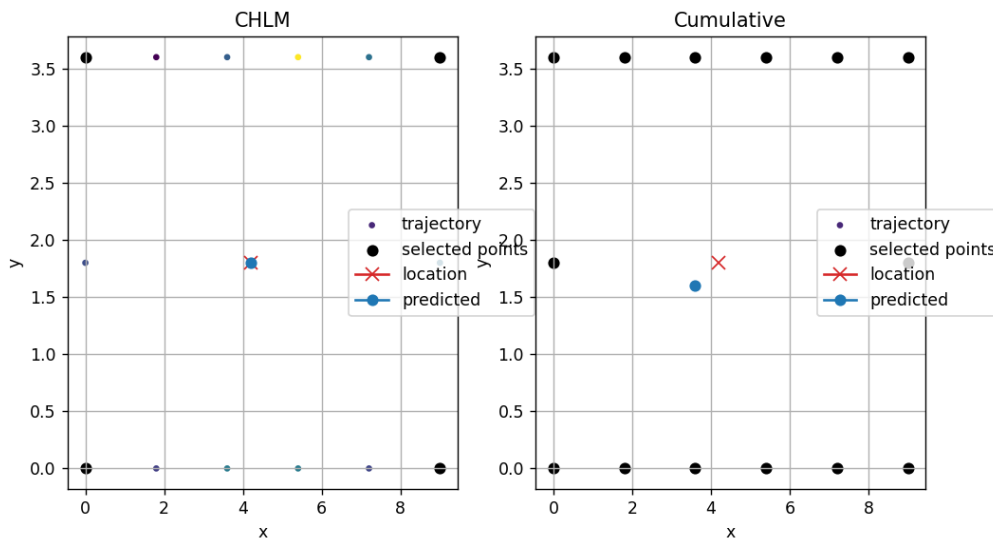


Figure 5.1. Estimation using Convex Hull Modified (a) and Cumulative Methods (b)

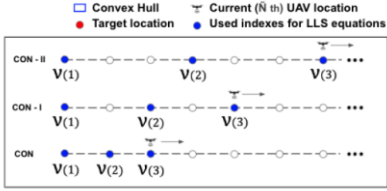
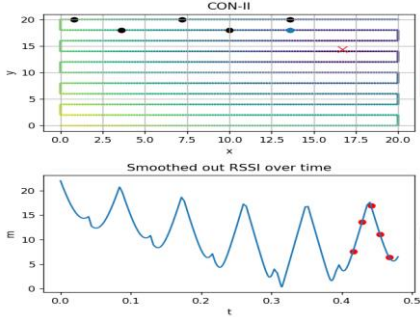
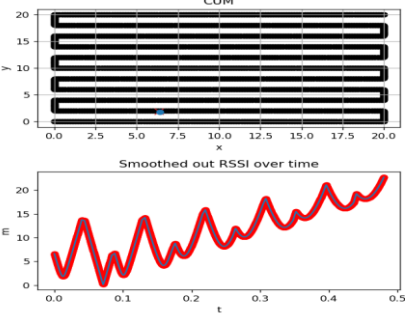
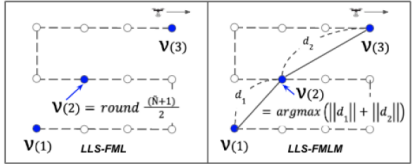
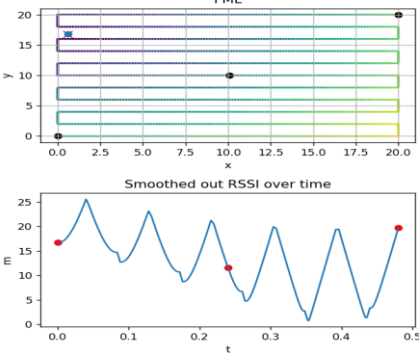
Kwon et al. approached the problem with 5 mathematical methods and static and dynamic approaches.

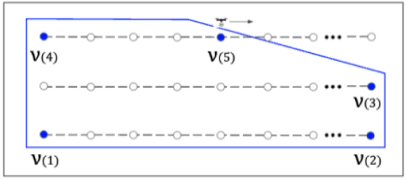
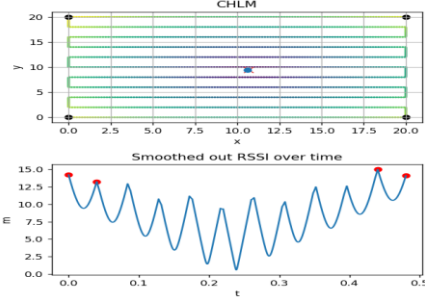
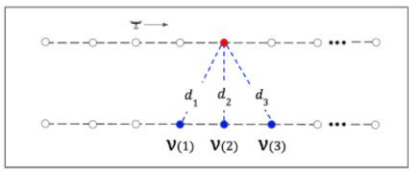
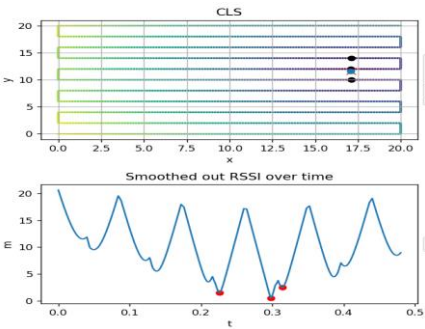
1. Consecutive three-point (CON);
2. Cumulative all-points (CUM);
3. First-mid-last points (FML);
4. Convex Hull Modified (CHLM);
5. Closest three-points (CLS).

We selected the most successful methods. First, we used the DRL approach, as it was more successful. Secondly, we did not consider LLS-CON and LLS-CON-I, as LLS-CON-II had higher accuracy.

In the table, the method, brief description, and simulated demonstration are shown. For figures, the upper figure shows the UAV's 2D path, starting at (0, 0) and ending at (20, 20). The transmitter's location is marked with a red cross and the 'location' legend. The predicted location is marked as a blue dot. The trajectory of the UAV is color-coded to display distance to the target. The farthest away values are yellow, and the closest ones are violet. The anchor points used for method selection are marked in black. The lower figure represents the distance from the UAV to the ground.

Table 5.3-A. Candidate Concepts.

Concept	Description	Reference	Replica
Method-1. Consecutive points (LLS-CON-II)	Choosing the triple of consecutive points based on the relative residual. The anchors are spaced out by 2 other points.	 (a) LLS-CON	
Method-2. Cumulative points (LLS-CUM)	All N points are selected.	 (b) LLS-CUM	
Method-3. First-Middle-Last points (LLS-FML)	Choosing the triple of points based on the maximum possible physical distance between them.	 (c) LLS-FML	

Concept	Description	Reference	Replica
Method-4. Convex Hull Modified (LLS- CHLM)	4 to 5 points are chosen so that they generate a convex hull	 (d) LLS-CHLM	
Method-5. Closest- three points (LLS- CLS)	Choosing 3 points that are closest to the target	 (e) LLS-CLS	

5.3.2 Weighted Trade-off Study

Table 5.3-B. Weighted Trade-off Matrix

Criterion	Metric / target	Weight	CON-II	CUM	FML	CHLM	CLS
Number of inputs	Number of points in input (0 = all datapoints, 10 = 3 datapoints)	0.05	10	0	10	5	10
Computation complexity	Runtime, efficiency (0 = complex, 10 = simple)	0.05	10	5	10	8	10
Flight distance	At what point in the drone flight can the accuracy threshold be reached	0.2	6	10	4	8	2

	(0 = longer flighttime, 10 = fast flighttime)						
Estimation accuracy	Is the model accurate (0 = high error, 10 = robust)	0.35	3	6	7	6	10
Reliability	Do estimation changes often (0 = unreliable, 10 = highly reliable)	0.35	10	7	0	7	0
		1	6.75	6.8	4.25	6.8	4.9

5.3.3 Selected Concept and Rationale

Based on [5], Method-1 is one of the most robust methods, but it is also very useful to work with average-sized RSSI datasets. It keeps the number of inputs to a minimum (3 points for the estimation), which leads to low computational complexity. Unfortunately, the usage of the one-dimensional consecutive points method leads to high inaccuracy of the RSSI prediction, as it tends to leave large gaps between three samples. Thus, it is very dependent on the dimensions of the testing environment, as an increased traversal path can lead to higher inaccuracies.

Again, in [5], Method-2 is similar to Method-1, but it accumulates all the RSSI measurement points in one matrix. Thus, we give weight 0 to the number of inputs. The computational complexity is naturally increasing, as all points are being simultaneously kept for calculation.

Method 3 is similar to Method 1, but it uses the three points at the farthest distance between them. This method leads to poor accuracy, but it is very computationally simple and robust.

Method 4 showed the balanced approach. It is fairly complex and takes a relatively fast flight time. The main disadvantage is that it shows the average error rate, but compared with other methods, it can be neglected.

Method 5 is the most unpredictable, but it shows great robustness. It is simple, but it is slow and takes the whole flight time to propose a solution. In the end, we are met with only one approximate result, as this method is not iterative.

In the given application, we are searching for highly reliable and accurate algorithms. The number of input points can have a low impact on system performance. Since all algorithms rely on linear least squares, the computational complexity is approximately identical for all methods. Therefore, computation time does not significantly influence method selection and has a low weight in the trade-off analysis. Overall, based on [5] and the trade-off matrix, Convex Hull and Cumulative were chosen as the best fit for the given application.

6. Design Iterations and Decision History

Table 6-A. Major Design Iterations

Iteration /version	Issue discovered	Alternatives considered	Decision made	Trade-off accepted	Evidence of improvement
ITE-1 ITE-5	Weak router signal; Weak internet connection decreases sampling frequency	Use a new router; Find a field with stable internet connection for high sampling frequency	A new router acquired; a field with good internet access is chosen	A new field with good internet connection is smaller, decreasing number of inputs	Appendix F, Table F-2
ITE-2 ITE-3 ITE-5	There is no clear relationship between distance and RSSI; data is difficult to interpret	Increase sampling distance to make difference in RSSI more clear	Sampling distance increased, reading-position sync approach implemented	The number of inputs decreased. Flight distance increased.	Appendix F, Table F-2
ITE-3	Difficulties with mapping Wall signal introduces signal distortion	Try walk-and-stop, separate samples, and continuous (5.2)	Walk-and-stop implemented, continuous sampling is accepted	Estimation accuracy increased. Computational complexity increased	Appendix F, Table F-2
ITE-2	Weak internet connection decreases update rate so it is unusable	Venue of smaller size with good internet connectivity	The testing site was moved to an area of smaller size and height	Flight distance decreased. Reliability decreased.	Appendix F, Table F-2
ITE-4 ITE-5 ITE-6	The experiment does not satisfy requirement 6	Using the air receiver instead of the ground receiver	Run the trial using the UAV	Switching to air receiver decreases position accuracy	Appendix F, Table F-2
ITE-4 ITE-5 ITE-6	Failure to properly log data when the receiver is	Address possible reasons such as: Poor wifi connectivity	Reject using a drone and continue experiments manually	Reliability of the samples increased. Flight distance becomes irrelevant	Appendix F, Table F-2

Iteration /version	Issue discovered	Alternatives considered	Decision made	Trade-off accepted	Evidence of improvement
	mounted onto a drone	Not suitable height Interference caused by the drone			

7. Final System Architecture

7.1 Experimental Architecture

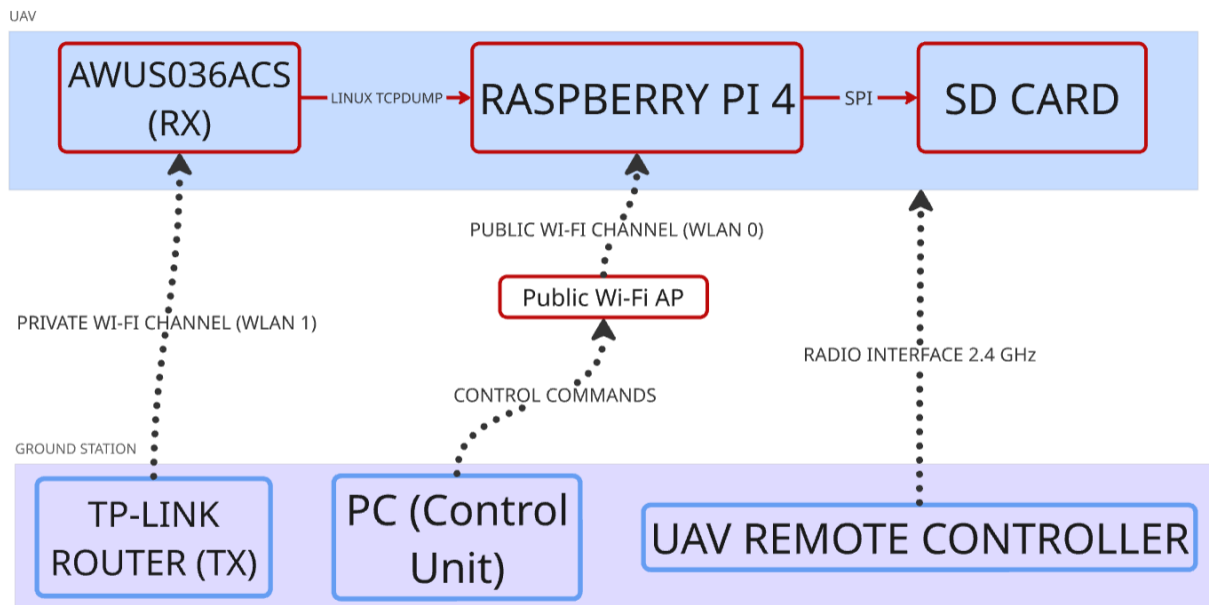


Figure 7.1.1 - Final System Block Diagram.

Table 7-A. Interface Summary.

Interface	Direction	Protocol / signal type	Rate / timing	Voltage / power	Owner subsystem	Notes
TX	AP TX → AP RX	Wi-Fi 5 (802.11n/b/g)	400 Mbps (max)	<20 dBm	Data Collection Subsystem	AP TX sends beacon packets to AP RX
RX	RX → Raspberry Pi	Linux tcpdump	300Mbps (max)	5V supply	Data Collection Subsystem	Gathering the RSSI and saving it on the SD card on the Raspberry Pi
Raspberry Pi	Raspberry Pi → SD card	SPI/flash memory	30 MB/s	N/A	Data Collection Subsystem	The SD card is inserted directly into the Pi's SD card slot
SD card	SD card → PC	USB 2.0/3.0 + SPI	30 MB/s	N/A	Data Collection Subsystem	The SD card is inserted manually into the PC for data analysis
PC	PC→Public Wi-Fi→Raspberry Pi	Wi-Fi 4/5	400 Mbps (max)	10-23 dBm	Control Subsystem	The PC acts as the control unit, sending commands to R.Pi

UAV	UAV Remote Controller r → UAV	2.4/5/5.8 GHz Radio Interface	1 Gbps (max)	<33 dBm	Control Subsystem	The UAV Remote Controller sends signals to manipulate the flight of the UAV
-----	----------------------------------	-------------------------------	--------------	---------	-------------------	---

Timing/latency budget:

Timing - 0.2 sec per RSSI beacon (5Hz)

Total latency - 0.3 sec per RSSI beacon

Power/resource budget:

Power - 5VDC, 3A (15W)

Field experiment setup

Experiment Preparation:

1. Testing Field
 - a. Measure and mark the boundaries of a testing field, keeping a 1.5 m distance from walls and objects to avoid unreliable results
 - b. Create a grid to see the anchor points
 - c. Remove obstructions from the testing area
2. Transmitter
 - a. Turn on the router
 - b. Place it inside the testing field and record the transmitter coordinates
 - c. Ensure router transmits the signal
3. Receiver
 - a. Connect receiver to a computer
 - b. Set receiver to monitor mode and connect it to router channel
4. Trajectory
 - a. Plan a square and a zigzag trajectory
 - b. For each path, record the sequence of anchor points

Trajectory data collection

1. Person A stands at the starting point, holding the receiver
2. Person B initiates the script for data collection.
3. Person A follows the predefined trajectory, pausing for 5 seconds at each anchor point.
4. Person B records the timestamp when Person A reaches each anchor point.

Path-loss data collection

1. Mark 4-5 points on a straight line from the transmitter, spaced out by more than 1 meter
2. Starting from the closest point, person A holds a receiver and stays for 5 seconds at every point
3. Person B records the timestamp when Person A reaches every point

UAV workflow

1. Roles: pilot, timekeeper, observer
2. Pilot connects receiver to UAV using zippers and tape
3. Timekeeper initiates the script for data collection
4. Pilot places UAV on the starting point
5. Pilot starts hovering UAV above every anchor point for 5 seconds, while another person records time when it had happened
6. Observers help the pilot navigate UAV for higher positioning accuracy

7.2 Data Analysis Architecture

1. Data pre-processing

Synchronization between anchor points and timestamps happens, and it is directed to a correct format.

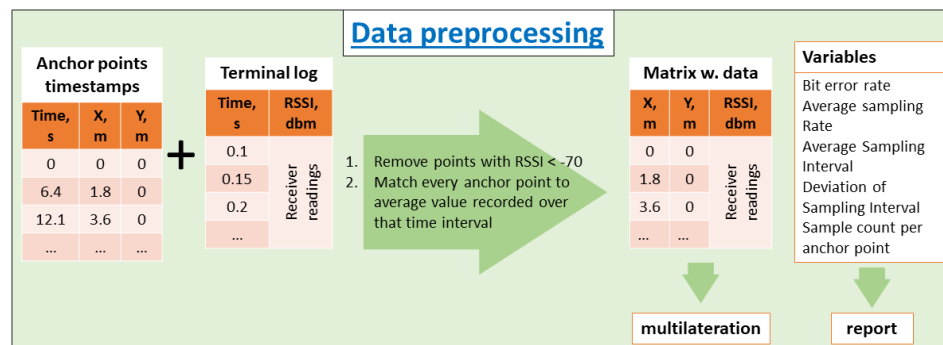


Figure 7.2.1 - Data Preprocessing Algorithm

2. Path-loss data collection

This is a model that allows transfer between RSSI and distance. Assumptions:

- a. Isotropic antenna
- b. RSSI is only dependent on pathloss exponent and distance to Tx source

1. Take 4-5 distance-rssi points

2. Estimate α by solving $Pl = Pl_0 + 10\alpha * \log\left(\frac{d}{d_0}\right)$, where $d_0=1m$ and $2<\alpha<4$ (For indoor conditions)

3. Multilateration

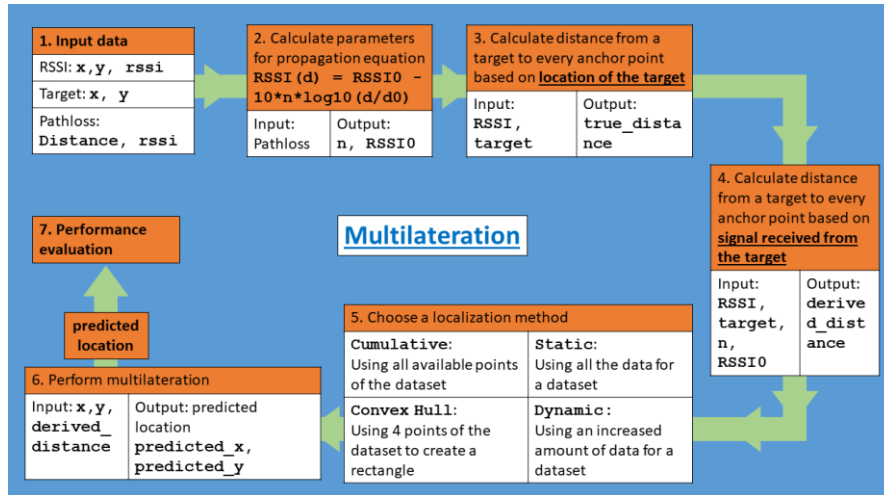


Figure 7.2.2 - Multilateration Concept

4. Point selection methods

Table 7.2-A: description of localization methods

Name	Meaning
Dynamic	Generates multiple predictions, updating the dataset from 3 to all points Defines whether predictions converge If yes: calculate average prediction after point of convergence If no: prediction is not possible
Static	Generates a single prediction based on the whole dataset
Cumulative	When given a dataset, uses all of the points for multilateration
Convex hull	When given a dataset, selects 4 of the points that form a geometric convex hull, and uses these points for multilateration

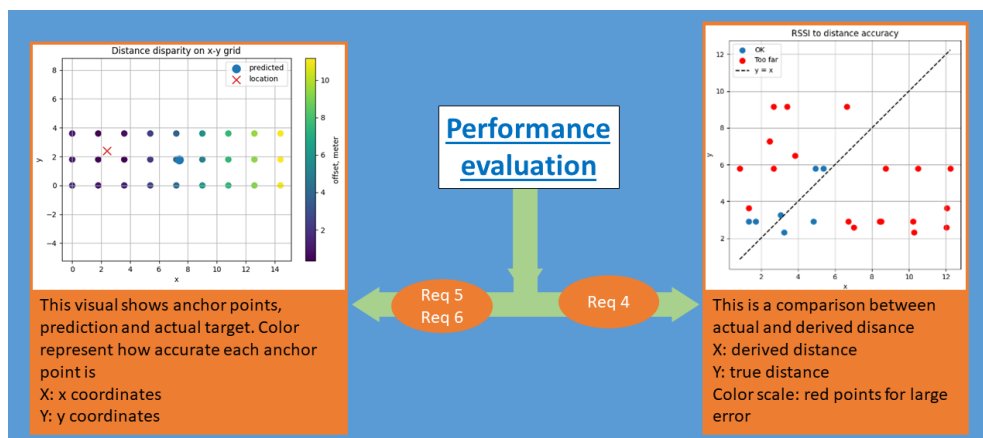


Figure 7.2.3 - Data Analysis Performance Evaluation

8. Detailed Design and Implementation

8.1 Hardware design

This section describes the hardware design of the setup.

In Figure 1, we implemented the receiving side of the experiment. It consists of a Raspberry Pi 4 Model B and an AlfaNetwork AWUS036ACS Wi-Fi transceiver attached to it via USB Type-A 3.0 port. The transceiver is set to the monitor mode, meaning it can only act as the receiver and scan for all existing networks within its operational band of 2.4 GHz (Wi-Fi). Our goal was to make it scan for the packets from only one dedicated TX, in our case, the conventional Wi-Fi router.



Figure-8.1.1. RX side of the design. Raspberry Pi 4 Model B equipped with the Alfa Network AWUS036ACS Wi-Fi transceiver. Mounted on an UAV during the experiment alongside a power supply. The SD card is inserted in the Pi beforehand and serves as Raspberry Pi OS (Raspbian) repository in which the software design can be implemented



Figure 8.1.2. TX side of the design. TP-Link Archer A64 is a conventional Wi-Fi router. It is used as the transmitter of the Wi-Fi packets, also known as beacons. Thus, the router may or may not be left as an idle device by not connecting to any existing network. Either way, the beacons will always be present in the Wi-Fi packet transmission.

8.2 Software/firmware design

In this section, we will describe the software side of the design.

As it was mentioned earlier in Section 8.1, we need to actually make the AlfaNetwork scan for only one transmission channel - the router beacons. Luckily, the Raspberry Pi OS, which is based on the Linux kernel, proposes a ***tcpdump*** utility. It is a command-line packet analyzer and sniffer tool used to capture and inspect network traffic in real-time. In *tcpdump*, a header format known as *radiotap* can provide all the necessary metadata of the packets that our hardware has captured. It provides per-packet information *not* transmitted over the air, such as **signal strength (RSSI)**, frequency, data rate, and antenna usage. By setting *tcpdump* to the MAC address of the Wi-Fi router, we can scan only this router and ignore the other channels. By having all the necessary information about the packet sniffing, we can actually start to make the script.

Firstly, we need the coding environment in which the script can be implemented. The choice of Python seemed the most obvious because of its great compatibility with the Linux kernel. Thus, the Raspberry Pi was connected to the PC via the Remote Python feature. In Section 7, Figure 1, this is represented as the arrow from the PC to the Raspberry Pi through the Public Wi-Fi Access Point. The Remote Python sets an SSH protocol interpreter that can access the Raspberry Pi from a PC by retrieving the IP address of the latter given by the Public Wi-Fi Access Point. By establishing a connection, we can exchange the scripts, files, and other information using the *scp* command.

The necessary scripts to set up an experiment are the following:

```
#!/bin/bash
SCRIPT_NAME="start-mon.sh"
SCRIPT_VERSION="20251022"
# Purpose: Start and configure monitor mode on the provided wifi interface
# Usage: $ sudo ./start-mon.sh [interface]
...
exit 1
fi
```

Figure-8.2.1. **Monitor Mode** script. Sets the AlfaNetwork receiver into monitor mode. The script is written in Shell. The full script can be accessed in Appendix D.

```
import subprocess, csv, re, time
INTERFACE = "wlan1mon", ROUTER_MAC = "32:ab:6a:68:e2:4a", CSV_FILE = "rssi_log.csv", SAMPLE_INTERVAL = 0.2 #5Hz
...
last_sample_time = now
```

Figure-8.2.2. RSSI logging script. Activates the ***tcpdump radiotap*** for a dedicated TX channel and

allows us to retrieve the **RSSI** value in a CSV format. The full script can be accessed in Appendix D.

8.3 Mechanical / packaging design (if applicable)

The mechanical design part involved 3D-printed casings for hardware, namely, the Raspberry Pi and the power supply.

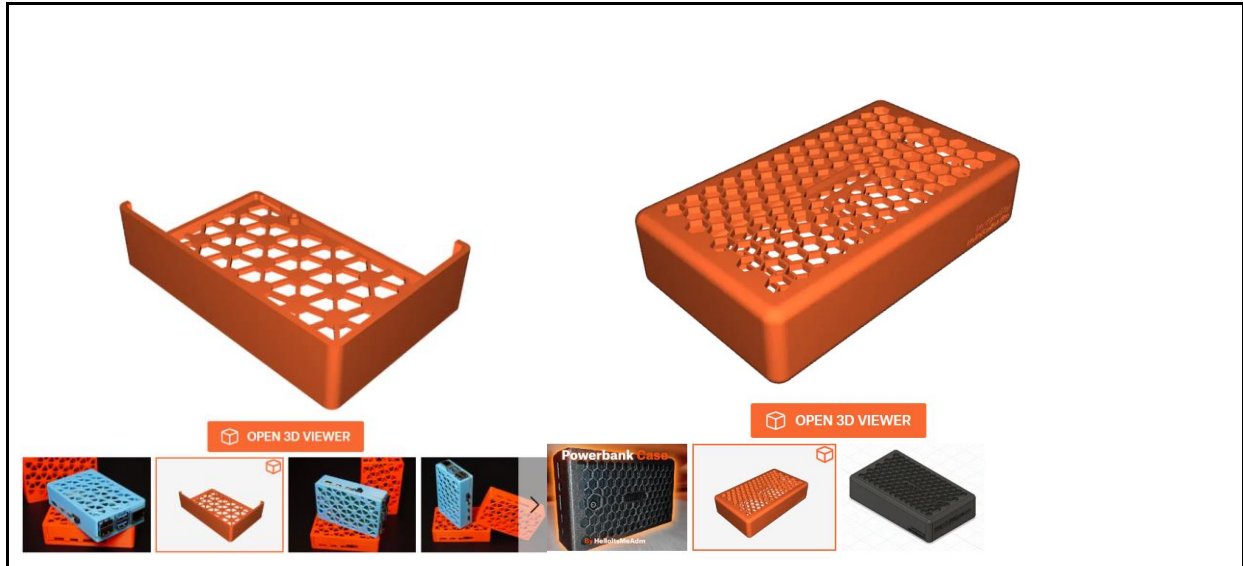


Figure 8.3.1. CSL models for packaging design

8.4 Prototype realization and integration



Figure 8.4.1. UAV equipped with all the hardware in printed casings.

8.5 Final bill of materials and design-for-manufacture / assembly notes

The Table 8-A reflects the ideal Bill of Materials. Refer to the Table 10-C for the expanded Bill of Materials.

Table 8-A. Final Bill of Materials (Total cost of the project without risk cases)

Part No.	Description	Qty	Unit cost	Supplier / lead time	Notes	Actual cost
RX AP	Wi-Fi AP ALFA Network AWUS036ACS	1	21 990	Ruba Networks	-	21 990
RPI-1	Raspberry Pi 4 Model B	1	62 500	Raspberry Pi	Borrowed from the university laboratory	0
UA V-1	DJI Mavic PRO	1	300 000	DJI	Borrowed from a local student	0
SD-1	MicroSD Samsung Endurance	1	19 990	BM Trade	-	19 990
FIL-1	ESUN PLA+ Filament	1	10 000	-	Used for the 3D-printed casings, borrowed for free	0
AD P-1	Wi-Fi adapter TP-LINK Archer A64	1	29 000	TP-Link	Borrowed from the university IT Office	0
PST-1	Poster printing	1	2 500	-	-	2 500
BA T-1	Powerbank USB-C 5V 3A 5000 mAh	3	5 000	-	Team member's personal powerbank	0
Total cost:			450 890 ₹	Actual cost:		44 480 ₹

9. Verification, Validation and Experimental Results

Table 9-A. Requirements-to-Test Results Matrix.

Req ID	Requirement	Test ID	Verification method	Equipment / tools and accuracy	Target	Measured result	Verdict	Evidence ID
REQ-1	The system shall collect RSSI samples at predefined UAV trajectory points.	TEST-01	Field experiment	Transmitter; Receiver; / Standard deviation is 0.9 between anchor points	≥ 20 measurements per anchor point	23 measurements per anchor point	Pass	EV-301
REQ-2	Hardware should receive WiFi packages consistently	TEST-02	Data analysis	Laptop / average sampling rate of 4.65 Hz	Average sampling interval = 0.5 s	Average sampling interval = 0.3 s	Pass	EV-302
REQ-3	The algorithm should implement data processing to increase efficiency	TEST-03	Comparison of results when data processing is (not) implemented	Laptop	An improvement in the performance metric	28% improvement	Pass	EV-303
REQ-4	The system shall accurately convert RSSI to distance	TEST-03	Field experiment	Transmitter; Receiver; / Accuracy is 0.1 m	$\geq 70\%$ of points within error threshold	70.63% of points within threshold	Pass	EV-304
REQ-5	The system shall estimate the location of a transmitter based on a ground path	TEST-05	Error between predicted and real target	Laptop	The predicted location shall lie within one grid cell of the true transmitter position & Localization error should be less than 15% of the testing area diagonal	Predicted location is within 1 grid cell + predicted location error is 15% of the diagonal	Pass	EV-305
REQ - 6	The system shall estimate the location of a transmitter based on an aerial path	TEST-06	Error between predicted and real target	Laptop		Predicted location is not within 1 grid cell +	No Pass	EV-306

						error>15% of the diagonal		
--	--	--	--	--	--	---------------------------	--	--

Table 9-B. Test Campaign Summary.

Test / experiment	Date	Owner(s)	Setup	No. of trials	Key result	Observed issues	Follow-up action
TEST-01	12.02	Tamerlan	Prepare the experiment Plot the readings over timestamps; Achieve a scatterplot without interruptions and pauses	1	Achieved connection between RX and TX REQ-1 is satisfied	Low range of TX	Chose more advanced and modern version of TX
TEST-02	18.02; 3.04	Team	Divide number of samples by run duration Confirm the logging frequency for all the experiments	3	Consistent accurate recordings REQ-2 is satisfied	Difficulty interpreting datapoints. Values lower than -70 suggest loss of line-of-sight or multipath propagation, and do not depend on distance	Data recording framework is developed. Delete the points to minimize inaccuracy and error
TEST-03	14.03	Firuz	Data analysis	6	Pre-processing improves results REQ-3 is satisfied	Points with large offsets can bias data and impact accuracy	Create a metric to measure how many anchor points are not biased
TEST-04	14.03	Firuz	Data analysis	6	The propagation model creates enough unbiased points REQ-4 is satisfied	-	Move on to the req-5

Test / experiment	Date	Owner(s)	Setup	No. of trials	Key result	Observed issues	Follow-up action
TEST-05	3.04	Team	Field experiment	7	Worst error is 25% Best error is 0% REQ-5 is satisfied	For zig-zag pattern, error is higher than 1 m	Preparation for a UAV run
TEST-06	4.04	Team	Field experiment	2	Possible causes: interference from the drone inadequate height inadequate antenna orientation Result: low prediction accuracy and biased data	REQ-6 is not satisfied	Perform design iteration and research improvements to the experimental setup to achieve the requirement (future)

10. Risk Management, Schedule, Budget, and Procurement Outcomes

10.1 Final Risk Register

Table 10-A. Risk Register with Outcomes.

ID	Risk	L	I	RPN L×I	Mitigation	Did it occur?	How handled	Residual risk / limitation
RSK-1	Radio wave interference	3	5	15	Change the testing environment to an interference-free environment Tune receiver sensitivity	Yes, in the confined spaces, the waves interact with the walls, which impacted to the results	We moved our experiment to larger spaces, such as a ballroom, where there was more space.	Minor interference may still occur due to external signals
RSK-2	Battery drains before completing the full trajectory	1	3	6	Shorten path Reduce computational load Constant battery health check	Yes, the drone could fly for no more than 25 minutes	We took two batteries for the drone and charged them one by one. Also shortened the path	Batteries still have limited capacitance, and minimize experiment time
RSK-3	Collected data contains noise or corrupted samples	2	4	8	Choose optimal altitude Apply filtering Calibration of the system before flight	Yes, due to environmental factors, there was noise	We did the calibration, and choose more optimal altitude	There is still noise, but it doesn't impact the overall results
RSK-4	Incompatibility between the Raspberry and the RSSI sensor	2	5	10	Troubleshoot the software installed on the Raspberry Pi	No	We updated and configured the required drivers and consequently solved the issue	There are no limitations and issues with Incompatibility between the two equipments

RSK-5	The power of Tx is not high enough to reach the UAV	1	3	3	Choose optimal altitude Increase the transmission power within the allowable limit	No	We chose the optimal attitude and configured the UAV to follow it	No issue
RSK-6	UAV trajectory is unstable and non-reproducible	3	5	12	Automatize the flight using additional hardware Limit testing facility dimensions to make the flight reproducible	Yes, but this issue was quickly fixed	We could configure the drone flight time and attitude, which stabilised the drone trajectory	There still possible that there is instability, but it didn't impact significantly
RSK-7	The UAV may not be delivered in time	2	4	8	Order the UAV early Ask other students for the UAV Look for rent options	No, the UAV was delivered on time	Ordered early	There are no risks

10.2 Milestones Planned vs. Actual

Table 10-B1. Milestones and Completion Evidence. Fall 2025.

Milestone	Planned date	Actual date	Owner	Exit criteria	Status	Evidence
Concept & Requirements development	Week 3	Week 3	Firuz	Draft problem, definition ready, Team formed	☐	Submitted in the defence report/presentation in FALL 2025
Literature Review completed	Week 6	Week 6	Firuz	Initial list of studies	☐	Submitted in the defence report/presentation in FALL 2025
Initial Simulation Results	Week 7	Week 7	Firuz	Model implemented	☐	Submitted in the defence report/presentation in FALL 2025

Milestone	Planned date	Actual date	Owner	Exit criteria	Status	Evidence
Finalise hardware	Week 10	Spring 2026. Week 2	Tamerlan	The setup is defined	☐	Final Report Section 8
Final Demo & Report	Week 14	Week 14	Team	All major tasks completed	☐	Submitted in the defence report/presentation in FALL 2025

Table 10-B2. Milestones and Completion Evidence. Spring 2026.

Milestone	Planned date	Actual date	Owner	Exit criteria	Status	Evidence
Hardware Assembly	Week 5	Week 4	Tamerlan	The setup is assembled and tested for the first time.	☐	Appendix D, Figures D1 and D2
Bench testing	Week 8	Week 6	Balnur	First RSSI measurements are taken. Mistakes are analyzed.	☐	EV-1001
The localization algorithm is updated	Week 9	Week 9	Firuza	The algorithm is updated for the requirements of the project	☐	Section 8 Appendix D
Final testing	Week 10	Week 12	Zhomart	Complete RSSI dataset and completed system setup. The algorithm works precisely.	☐	Section 9 EV-305
Final Demo & Report	Week 14	Week 13	Team	Final submission	☐	Final Report EV-1002

10.3 Budget, Procurement, and Substitutions

Table 10-C. Bill of Materials and Procurement Summary.

Part No.	Description	Qty	Unit cost	Total	Alt. part / substitution	Supplier / lead time	Impact of substitution
RX AP	Wi-Fi AP ALFA Network AWUS036ACS	1	21 990	21 990 KZT	ALFA Network AWUS036ACHM	Ruba Networks	-
SD-1	MicroSD Samsung Endurance	1	19 990	19 990 KZT	Any other Endurance MicroSD	BM Trade	-
FIL-1	ESUN PLA+ Filament	1	10 000	10 000 KZT	-	-	-
ADP-1	Wi-Fi adapter TP-LINK Archer A64	1	29 000	29 000 KZT	Any other TX router	TP-Link	-
PST-1	Poster printing	1	2 500	2 500 KZT	-	-	-
ANT-1	2 dBi RP-SMA 2.4 GHz antenna	1	2 000	2 000 KZT	7 dBi RP-SMA 2.4 GHz antenna	China	Replaced the damaged antenna to make RX AP functional again. Increased signal coverage.
BAT-1	Battery	3	5 000	15 000 KZT	Powerbank with a bigger capacity	-	Powerbank was used as a more safe and stable alternative

Budget status vs. plan: *Substitution parts are used in some cases, in italics. Please refer to Table 10-C for further explanation.*

Part No (PN)	Description	Qty	Unit Cost	Total	Status
--------------	-------------	-----	-----------	-------	--------

RX AP	Wi-Fi AP ALFA Network AWUS036ACS	1	21 990	21 990 KZT	Purchased
SD-1	MicroSD Samsung Endurance	1	19 990	19 990 KZT	Purchased
FIL-1	ESUN PLA+ Filament	1	10 000	10 000 KZT	Not purchased
ADP-1	Wi-Fi adapter TP-LINK Archer A64	1	29 000	29 000 KZT	Borrowed from the IT office, not purchased
PST-1	Poster printing	1	2 500	2 500 KZT	Purchased
ANT-1	7 dBi RP-SMA 2.4 GHz antenna	1	2 000	2 000 KZT	Purchased
BAT-1	Powerbank	1	5 000	5 000 KZT	Team member's personal device, not purchased
Total spending	46 480 KZT				

Change-control summary: *In conclusion, several parts were substituted as part of the risk or cost reduction. That is, the 2dBi 2.4 GHz antenna supplied as part of AlfaNetwork AWUS036ACS Receiver was changed to the 7dBi RP-SMA antenna from a different manufacturer. The power supply for the Raspberry Pi device was chosen in the form of a powerbank device instead of a standalone battery, which is more dangerous and hard to use. Both substitutions did not affect the setup negatively. In some scenarios, the changes produced positive results.*

11. Professional Responsibilities and Broader Impacts

This project evaluates RF-signal localization algorithms using a small UAV in an indoor bench environment to validate simulation results. The following subsections discuss the measures adopted to mitigate safety risks and ensure compliance with ethical, security, and accessibility standards.

11.1 Public Health, Safety, and Welfare

UAV flight might introduce both physical and electronic *hazards*:

- Rotating propellers
- Issues during manual handling
- The risk of uncontrolled descent or collision due to battery depletion (which is usually limited to 30 minutes)
- Potential RF/equipment interference
- Propeller exclusion zone: an appointed area during take-off/landing

To ensure smooth and safe operation during the experiment, we plan to implement these *controls*:

- Designated test zone: a cleared area to safely conduct the experiment
- Propeller exclusion zone: an appointed area during take-off/landing.
- Training: The team will complete UAV handling training and obtain a formal certificate from the Civil Aviation Authority. The training certificate will be obtained from the official website of CAA.
- PPE: All members involved must follow safety precautions during the testing.
- Prior supervisor approval is a must before field testing.
- Pre-flight checklist: Each experiment will follow a structured checklist to verify the equipment readiness and emergency procedures before the experiment.
- A low-traffic area: UAV flights will be carried out in a low-traffic indoor area to minimize exposure to others.

Evidence:

- Training: will be submitted.
- Pre-flight checklist: will be submitted.

11.2 Ethical and Professional Responsibilities

The system processes data from hardware sensing. No personal data or identities are collected. However, any signal-based localization may have dual-use potential.

On AI usage: The AI-assisted Large Language Models (LLMs) were used for the primary purpose of assisting the project progress. The LLMs did not substitute the work of the team members and acted as an assisting tool. The report is written primarily by team members.

Therefore:

- The system will not be used to track individuals or non-consented sources.
- The scope is strictly academic, with the focus on performance evaluation.
- A test does not interfere with or impact random people around who have not consented.

- The data collected will not contain personal information and will remain purely statistical content.
- From an environmental perspective, all batteries used and damaged equipment will be properly recycled/disposed of.

All ethical compliance will be overseen by the project supervisor, who is responsible for approval of all experimental procedures. Any proposed changes must remain within the defined project scope and be thoroughly reviewed. If necessary, the procedures will be further checked to ensure full compliance with the university's code of conduct.

11.3 Security and Privacy

Data will be stored locally in CSV and text files. There is no internet-connected remote control or cloud-based data transfer. Hence, the data is secure and not exposed to unauthorized parties. Security risks are minimal, with the main risk being an accidental file deletion. For that reason, version control will be implemented to track changes and allow them to be reviewed later.

11.4 Accessibility and Usability

Project documentation and presentation materials will be designed to be easily understood by both the general public and the evaluators assessing the work. A standard, readable font (Times New Roman) and font size (12 pt) will be used in the report. All figures, tables, and plots will include clear labels and descriptive captions to ensure their content is available. Moreover, the algorithms used will be provided. The final report and presentation slides will be submitted in a standard PDF reader.

11.5 Environmental, Economic, Social, Global, and Cultural Factors

From an **environmental perspective**, this project should have a minimal impact. Equipment consumes a low level of electrical power, and all experiments were conducted within university facilities due to **economic considerations**. As well as the usage of open source resources, it eliminates recurring additional licensing costs and simplifies the deployment.

The most significant **Social and global impacts** of this project are its potential to be scaled up in several applications, for example, in search-and-rescue operations by potentially reducing the time to locate in wilderness or disaster scenarios.

Cultural standpoint: This project was conducted only within an academic context as initially defined.

12. Team Organization, Collaboration, and Individual Contributions

Table 12-A. Team Roles and Responsibilities.

Member	Primary role	Secondary role	Major technical ownership	Leadership responsibility	Evidence ID
Balnur	Documentation	Analysis of the data	Assessment of the experiment	Analysis of the results	EV-305
Firuza	Team leader	Algorithm development	Development of a localization algorithm	Distribution of the tasks and overall coordination of the team members	EV-303
Tamerlan	Hardware engineer	Software support	Hardware setup, RX/TX connectivity, Raspberry Pi RSSI script development	Troubleshooting hardware issues	Appendix D, Figure D-5
Kassymzhomart	Integration of the system	Testing of the system	UAV setup, conduction of flight	Coordination of testing flights with UAV and compliance with safety requirements.	Appendix D Section 8

Table 12-B. Teamwork Evidence Matrix.

SO5 element	Project-specific evidence	Where shown in report / appendix	What changed because of team interaction
Leadership	The team leader supervised the other members and coordinated the tasks between them	Appendix C Section 12	Better coordination between team members
Collaborative environment	Regular meetings and discussions with team members, and uniform distribution of the workload	Section 2.2 Appendix C	High motivation of the team members and high efficiency
Goals	Determine the location of the transmitter using the receiver on the UAV	Section 2.2	Set goals were achieved

SO5 element	Project-specific evidence	Where shown in report / appendix	What changed because of team interaction
Task planning	Planning of the tasks on meetings and allocation of the roles and tasks among team members	Appendix C	Rise in team efficiency and reduction of the task delay
Objectives met	A major part of the goals was met successfully. RSSI samples collected and accurately converted to distance. The location of the transmitter was determined	Section 1 Section 10	Increased accuracy of the collected data

Table 12-C. Individual Contribution Log.

Member	Key tasks completed	Deliverables produced	Dates / period	Supervisor verification / evidence
Balnur	RSSI data collection, Data analysis	Process of output data	Weeks 3–10	EV-305 Appendix C
Kassymzhomart	UAV system setup, conduction of the flight during the experiment	Integrated UAV system	Weeks 5–8	Appendix D Section 8
Tamerlan	Hardware Configuration	Raspberry Pi, RX and TX connection, RSSI logging script	Weeks 2–8	Appendix D Figure D.5 Figure D.6
Firuza	Coordination of the project and experiment; Also development of the localization algorithm	Algorithm development	Weeks 5–6	Appendix D EV-3

Team Charter - The team has gathered to implement a Capstone Project with all needed Engineering Evidence and in compliance with academic standards. The Project serves as a proof-of-concept of the RSSI Localization Algorithms. The end goal of the Project is to create a working prototype of the concept. The Project can be scaled towards industry and private businesses. The team of 4 students cooperatively worked towards the goals through meetings, including online ones. The experiments were done on a dedicated testing site. The decision-making process was done via cooperation and understanding of each students' needs and abilities.

Meeting Cadence - Refer to Appendix F, Table F-1

13. Use of Prior Course Work and New Knowledge Acquired

Table 13-A. Prior Course Work Applied.

Design task	Prior course / topic used	How it was applied	Evidence in design
RSSI to distance conversion	Wireless Communications	Applied the formula to convert dBm data to estimated distances.	Section 5
Hardware assembly	Digital logic design, Microprocessors Systems	Applied when configuring the Raspberry Pi 4 and AlfaNetwork RX.	Section 8 Appendix D
Python functions	Programming For Engineers; Algorithms and Data Structures.	Wrote Python scripts for path loss model fitting. Also created a function to keep records of timestamps	Section 8 Appendix D
Experimental results and deliverables	Core course Lab classes	Applied basic knowledge of experimental setup and workflow to define objectives.	Section 5 Appendix E
Technical writing	Technical Writing reports and formal wiring	Applied basic principles of academic writing to ensure clear communication to different types of audience	Section 0 Section 1 Section 2

Table 13-B. New Knowledge Acquired and Applied.

Knowledge / skill learned	Why it was needed	Source used	How it changed the design or test process
3D Printing Skill	To print the casing for the mounting of a receiver on the UAV	SolidWorks, self-learning, documentations	Casing was used to protect the parts from mechanical damage and to meet safety measures.
UAV Flight Regulations	No prior knowledge of UAV regulations. But legal compliance is a must for the project	Kazakhstan Aviation Regulations/International UAV Regulations	Helped to conduct flights smoothly within the indoor environment
Understanding of Linear Least Squares	Create an algorithm to estimate	[1], [2], [5]	Implementation of methods from the source made the

Knowledge / skill learned	Why it was needed	Source used	How it changed the design or test process
(LLS) localization and anchor point selection strategies	transmitter position in real time		project more realistic and introduced robust localization methods
Software utilities designed for Wi-Fi Standard	To implement a working setup	Github, Linux repositories	The testing was made possible with the introduction of software control to collect RSSI data
Encryption of the communication	To comply with the FCC regulations	FCC/ITU regulations	The uplink channel to collect RSSI data became secure, adding credibility to the Engineering Evidence

14. Conclusions and Recommendations

This experiment was successful and we met all the requirements from REQ-1 until REQ-5, leaving only REQ-6 partially completed. As stated in the first requirement section, our system collects the RSSI samples at predefined UAV trajectory points(REQ-1), while hardware collects each packet in a Wi-Fi frame at a minimum frequency of 4 Hz (REQ-2). The next requirement is the filtering of the data through algorithms that implement data processing which consequently increase the efficiency(REQ-3). Fourth requirement is accuracy of the conversion of RSSI data to distance which requires that at least 70% of the samples must be accurate (REQ-4). Also the main target of the experiment, conversion of the RSSI to the distance which helps us to indicate the location of the transmitter during the ground experiment must work (REQ-5). There must be evidence that we indicated the location with less error. All these requirements were met successfully except the last one which was partially met. So in the end we needed to indicate the location of the transmitter during the aerial experiment, where the error must be less than 5%. Unfortunately due to factors such as noise and interference we couldn't maintain the low error rate.

For this project the factors such as cost, reliability and accuracy were considered in the design of the equipment. But due to the unavailability of the high quality equipment decreased the efficiency and accuracy of the results. Also due to low capacity of the battery of the UAV, the flight time significantly decreased which forced us to optimize the flight time. If we had more budget, it was possible to buy a modern UAV with more battery capacity. It impacted the realism of the experiment.

- Requirements throughout the REQ-1 to 5 are fulfilled, leaving only REQ-6 to be partially completed. The system collects all the samples (REQ-1), each packet maintained a rate above 4 Hz (REQ-2), successfully converted 70% estimation (REQ-3). The system collects decent data on ground (REQ-5), and conversion from RSSI to distance is done smoothly (REQ-4). REQ-6 is failed due to high interference during UAV flight.
- For this project cost/simplicity vs accuracy was also considered. High accuracy could have been achieved with more advanced hardware equipment.
- The primary limitation of the project was its sensitivity to noise interference and multipath propagation within the indoor setup.

Recommendation:

Track location → remove mapping from the /// → autonomous / on board

- The system should not be piloted manually; RX can be equipped with a live point position estimate.

The primary limitation of the project was its sensitivity to noise interference and multipath propagation within indoor conditions. It significantly impacted the accuracy of the RSSI values which directly impacted the distance calculation accuracy. Moreover the quality of the equipment also influenced the receiving signal quality. If we had a more advanced antenna, we could catch the signal more effectively and accurately.

For the future we recommend implementing digital signal processing algorithms that can get rid of the corrupted data which consequently will increase the accuracy of the input signal. It will filter the corrupted signal and reuse it which will positively affect the outcome.

15. References

- [1] Muhammad Atif et al. "UAV-Assisted Wireless Localization for Search and Rescue". In: IEEE Systems Journal 15.3 (2021), pp. 3261–3272. doi: 10.1109/JSYST.2020.3041573.
 - [2] Craig Vincent-Lambert, Anje Pretorius, and Bernard Van Tonder. "Use of Unmanned Aerial Vehicles in Wilderness Search and Rescue Operations: A Scoping Review". In: Wilderness & Environmental Medicine 34.4 (2023). PMID: 37923682, pp. 580–588. doi: 10.1016/j.wem.2023.08.022. eprint: <https://doi.org/10.1016/j.wem.2023.08.022>. url: <https://doi.org/10.1016/j.wem.2023.08.022>.
 - [3] Casey Smith et al. "UAS-Based Radio Frequency Interference Localization Using Power Measurements". In: Feb. 2024, pp. 1169–1183. doi: 10.33012/2024.19570.
 - [4] Marjo Heikkilä et al. "The Use of Unmanned Aircraft System for the Radio Frequency Interference Measurements". In: 2019 IEEE International Symposium on Measurements & Networking (M&N). 2019, pp. 1–6. doi: 10.1109/IWMN.2019.8805039.
 - [5] Hyeokjun Kwon and Ismail Guvenc. "RF Signal Source Search and Localization Using an Autonomous UAV with Predefined Waypoints". In: 2023 IEEE 97th Vehicular Technology Conference (VTC2023-Spring). 2023, pp. 1–6. doi: 10.1109/VTC2023-Spring57618.2023.10200783.
 - [6] Spire Global, "Understanding multilateration (MLAT) for more precise aircraft positioning free from interference," *Spire Aviation Blog*. [Online]. Available: <https://spire.com/blog/aviation/understanding-multilateration-mlat-for-more-precise-aircraft-positioning-free-from-interference/>. [Accessed: Apr. 11, 2026].
 - [7] Y. Shu et al., "Gradient-Based Fingerprinting for Indoor Localization and Tracking," in IEEE Transactions on Industrial Electronics, vol. 63, no. 4, pp. 2424–2433, April 2016, doi: 10.1109/TIE.2015.2509917.
- keywords: {IEEE 802.11 Standard;Wireless communication;Radio frequency;Sensors;Indoor environments;Received signal strength indicator;Calibration;Indoor localization;fingerprinting;WiFi;Fingerprinting;indoor localization;WiFi},

Appendix A. Engineering Standards Evidence

Table A.1. Engineering Standards Evidence.

Standard ID and title	Clause(s) used	Why applicable?	Design decision affected	How verified	Status
ITU Radio Regulations Chapter 2 Article 5: Frequency allocations	Footnotes 5.138, 5.140, 5.280, and 5.398A: ISM Band Allocation - 2.4 GHz (unlicensed band)	To ensure that Tx remains inside the ISM band - no out-of-band emission	Selection of operating frequency	Analysis of the experiment data (RSSI and attenuation) Review of the connection settings	☐
UN/DOT 38.3: Lithium metal and lithium ion batteries	Clauses: 38.3.4: Procedure and 38.3.2: Scope	To maintain safety and prevent hazards associated with the improper handling of battery packs	Selection of battery capacity, voltage, and chemical composition	Inspection of charging, temperature, and electrical specifications before the experiment	☐
FCC Part 15 Sub-part C	Section 15.247: Operation within 2.4-2.4835 GHz band	To ensure that a system operates within a certain frequency and on a limited transmission power	Uplink connection between Tx and Rx must comply with the standard	Review of connection settings, such as frequency, power of transmission	☐
ISO/IEC 27001:2013	Annex A.10: Cryptographic Controls	To securely store and protect the data	Data storage method selection, encrypted connection between Tx and Rx	Version-control storage and Password implementation on the uplink connection	☐

Appendix B. Multiple-Constraints Matrix

Table B.1. Multiple-Constraints Matrix.

Constraint	Metric / target	Rationale	Trade-offs considered	Outcome/ status	Evidence
General safety precautions	Zero incidents during the experiment Completed safety checklist	Ensuring safe operation is integral; it prevents damage and harm	Lower height of the flight is safer, but less realistic If pilots keep a safe distance from obstacles, it reduces the available flight area	The testing zone is isolated, precautions are taken, and UAV flight is controlled	Pre-flight checklist
Power/ Energy	UAV completes its full trajectory line	Battery capacity limits the flight time	Shorter trajectory decreases flight time and battery discharge, but also yields fewer data points for the experiment	UAV is powered throughout the experiment	Flight log
Performance accuracy	Localization error (5-10%) Robustness to interference	The system should provide a feasible localization solution	High-complexity algorithms yield more accurate results, but increase power consumption	Controlled indoor environment, configure the RX to receive only known TX	Comparison with reference work
Timing/ Schedule	Milestones are completed in accordance with the report	Following the schedule reduces the risk of possible delays	Time should be split between background research, conducting experiments, data analysis, and conclusion	The project is completed on time	Gantt chart, reports
Economic	The BOM is under 100 MCI	Limited funding	Expensive hardware can provide higher-quality results	Only essential materials are purchased	Updated BOM

Appendix C. Team Organization and Contributions

	Team roles	Responsibility	Contribution
Firuz	Team leader, development of algorithm	Coordination of the team members and development of algorithms	Distribute the tasks and development RSSI-based algorithm
Balnur	Data analytic	Analysation of data	Analysed the data extracted from the experiment and analysed the accuracy
Kassymzhomart	System integration engineer	UAV setup and control	Conducted the flight during experiment and checked the system operation
Tamerlan	Hardware engineer	Development and integration of data collection hardware setup	Designed experimental setup, RSSI logging algorithm and established connectivity between TX and RX

Our team adopted a collaborative management system, ensuring that each team member knew exactly what they needed to complete and by what deadline. Team leaders strictly assigned tasks to team members, meticulously monitored and reported delays and errors. All tasks and deadlines were recorded on a Gantt chart, allowing everyone to track future work, delays, and the contribution of each team member. We also held frequent team meetings to discuss topics and issues. This system helped us maintain a high level of efficiency and achieve the desired results in our experiments.

Appendix D. Design Evidence



Figures D.1 and D.2 - Full Experimental Setup

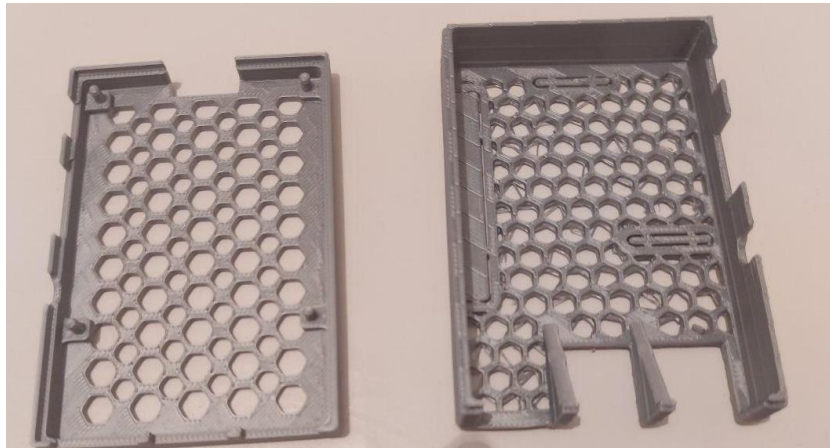


Figure D.3 - 3D-Printed casing for Raspberry Pi hardware setup



Figure D.4 - Receiver hardware setup - Raspberry Pi 4 Model B + AlfaNetwork AWUS036ACS

□ https://github.com/morrownr/Monitor_Mode/blob/b205d92f3f2fccac972ca3b6deb3426737ba8ed7/start-mon.sh

□ **Figure D.5 - AlfaNetwork AWUS036ACS Monitor Mode setup code**

```

import subprocess
import csv
import re
import time

INTERFACE = "wlan0mon"
ROUTER_MAC = "32:ab:6a:68:e2:4a"
CSV_FILE = "rssi_log.csv"
SAMPLE_INTERVAL = 0.2 #5Hz

cmd = [
    "sudo",
    "tcpdump",
    "-l",
    "-i", INTERFACE,
    "-e",
    "-vvv",
    f"wlan type mgt subtype beacon and wlan addr3 {ROUTER_MAC}"
]

proc = subprocess.Popen(cmd, stdout=subprocess.PIPE, stderr=subprocess.STDOUT, text=True)

pattern = re.compile(r"(-?\d+)dBm signal")

last_rssi = None
last_sample_time = time.time()

with open(CSV_FILE, "w", newline="") as f:
    writer = csv.writer(f)
    writer.writerow(["timestamp", "rssi_dbm"])

print("Logging RSSI... Press CTRL+C to stop")

while True:
    # read line if available
    line = proc.stdout.readline()
    if line:
        match = pattern.search(line)
        if match:
            last_rssi = int(match.group(1))

    now = time.time()
    if now - last_sample_time >= SAMPLE_INTERVAL and last_rssi is not None:
        ts_str = time.strftime("%H:%M:%S", time.localtime(now)) + f".{int((now%1)*1000):03d}"
        writer.writerow([ts_str, last_rssi])
        f.flush()
        print(f"{ts_str} RSSI {last_rssi} dBm")

    last_sample_time = now

```

□ **Figure D.6 - RSSI logging algorithm**

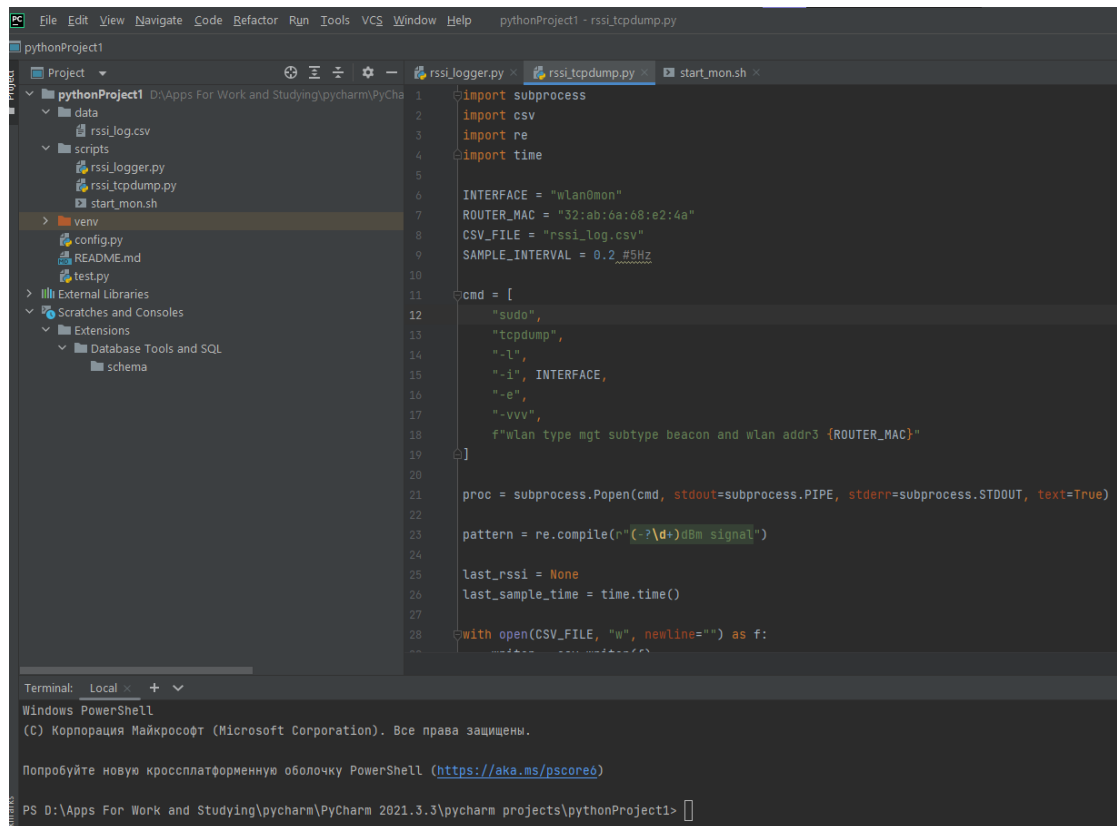
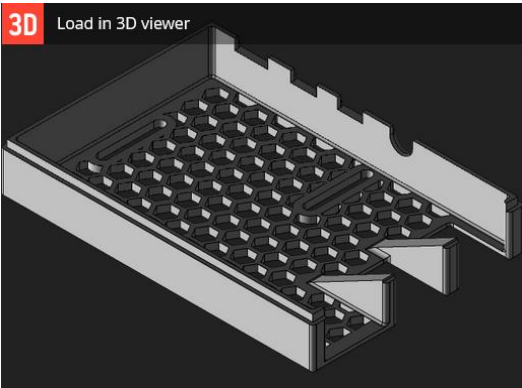
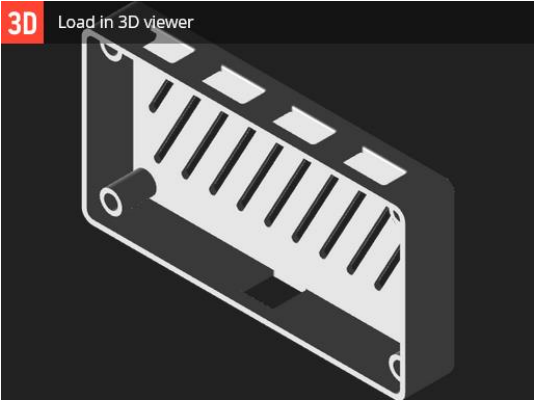


Figure D.7 - Hardware Setup Control working environment

Table D-1: Additional Links

Name	Links	Additional Materials
3D CAD Model for Raspberry Pi 4 Case	https://grabcad.com/library/raspberry-pi-4-case-5/details?folder_id=9456268	 3D Load in 3D viewer

3D CAD Model for Powerbank	https://grabcad.com/library/case-for-qc-usb-charger-xfw-kc42-4-1	 A 3D CAD model of a powerbank case, shown in a perspective view. The model is white with a black base and features a series of vertical slots on the front face. A red '3D' icon and the text 'Load in 3D viewer' are visible in the top left corner of the image.
DJI Mavic PRO Remote Control	https://mavic.kz/product/pult-du-dji-remote-controller-dlya-mavic-pro/	 A black DJI Mavic PRO Remote Control, shown from a top-down perspective. The remote features two joysticks, a central screen, and various buttons. It has a foldable design with two black antennas extending upwards and two black grips extending downwards.

Appendix E. Verification Evidence

Table E-1: Evidence links

ID	link
EV-201	Budget 3 appendixes https://docs.google.com/document/d/1XEnZkkW89SusZH5zLSgxljytqVr3gb6r/edit?usp=sharing&ouid=100558066136871526094&rtpof=true&sd=true
EV-301	https://docs.google.com/spreadsheets/d/1tmAPbQoJFNncSX4z7gKhynrWfemSLSZM-HX8Nn6q-Uz/edit?usp=drive_link
EV-302	https://docs.google.com/spreadsheets/d/18F9TrZHHJu7KibzaW4x3_d4WnituhCeFOOQis9dNhoOg/edit?usp=sharing https://docs.google.com/spreadsheets/d/187AsaYDyomFsSvyDrNi24_1R-Uf0UZHhK-kNYFupJ8Y/edit?usp=drive_link https://drive.google.com/file/d/1IOEjN9vNjF3hJkc8bPJ35zSsO6EQ3mOw/view?usp=drive_link
EV-303	https://docs.google.com/document/d/1c8my8ysnH5ZM_P_ovUImZI1g1iqyhq5nzQXLeTilpO8/edit?usp=drive_link
EV-304	https://docs.google.com/document/d/1TYuZwDa9VxKhamz4SIjliVF4M9oprI5KkepvLgAHULQ/edit?usp=drive_link
EV-305	https://docs.google.com/document/d/18NmA869ghsAMuQLXd_X7fckVxa6ueydFNd554zxnBTs/edit?usp=drive_link https://docs.google.com/spreadsheets/d/1RpP3Et9ciqD6u9U-UJzV_-rJ6fGvd5ldbWdPfUG63sA/edit?usp=drive_link https://drive.google.com/file/d/18Y91HM8qWzdK9405RsKubyRp7kruhvCI/view?usp=drive_link
EV-306	https://docs.google.com/spreadsheets/d/1hrqEKkfyfyt4YrOhphDjDwzGGJIXhpaqjHsZh70syEg/edit?usp=sharing https://docs.google.com/spreadsheets/d/1xujaiIU2WzjaDqAdgcD7zLz5xw_Y7Ig_3Ig-9c8U95s/edit?usp=sharing https://docs.google.com/spreadsheets/d/1xujaiIU2WzjaDqAdgcD7zLz5xw_Y7Ig_3Ig-9c8U95s/edit?usp=sharing
EV-1001	https://docs.google.com/spreadsheets/d/19gFreSebuoyJa4PYdSHOzXEZc1oPh_7CTxcduFF3vU/edit?usp=sharing
EV-1002	https://drive.google.com/drive/folders/14L5NBNr3caewRbXk_4NKTG1s1ByROV3?usp=sharing
EV-F01	https://docs.google.com/document/d/1lsMpXnz585vQqiKlgo4NIWAnv

	c0o50IhxJfngHOrw-o/edit?usp=drive_link
EV-F02	https://docs.google.com/spreadsheets/d/1KcVs8-oHPXXlfcM5UNiu5X7OilZx4JNhktZM9Uzy3Y/edit?usp=sharing
EV-F03	https://docs.google.com/spreadsheets/d/1XLRwXjJWlMnupaPptT3hjTyBO8LTw6tQ4uyKHmZwd-k/edit?usp=sharing
EV-F04	https://docs.google.com/spreadsheets/d/1XLRwXjJWlMnupaPptT3hjTyBO8LTw6tQ4uyKHmZwd-k/edit?usp=sharing
EV-F05	https://docs.google.com/spreadsheets/d/10mJvFwZvIAH6Ja_yQ4TndBiMwHw7G6ohgR4fjLt4dgE/edit?usp=sharing https://docs.google.com/spreadsheets/d/1KTE6OBKk3Ho_ijsbZnDCvs93orrRL-XaJBz-Y-1aPe0/edit?usp=sharing https://docs.google.com/spreadsheets/d/1U7QKSHAu2tB2dn5IFicURu-RfgANSj3zthYf5j-YZMo/edit?usp=sharing https://docs.google.com/spreadsheets/d/12ZMAI987bz6pA0DBd4C9eCa1OMs-2T_0rb-jAuGhSwo/edit?usp=sharing https://docs.google.com/spreadsheets/d/1a1CesguiA0lKSXf52iU1sH7e_D7Uz6yh0uYd7CZYlUA/edit?usp=sharing https://docs.google.com/spreadsheets/d/1HLd7RFk5HhkMXm9VS2ukg1wO4kZVQA2UQIoP2S9O_p0/edit?usp=sharing https://docs.google.com/spreadsheets/d/1lAjaUKwlEK1fMdyQLT4Pp9JiG9CT5FBI1QmZisTbU3M/edit?usp=sharing

Appendix F. Project Management Evidence

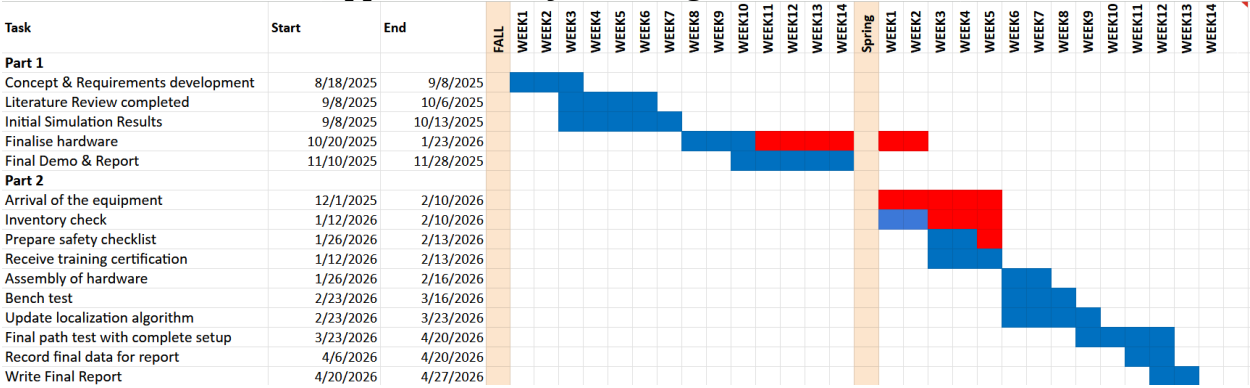


Figure F.1 - Gantt Chart

Table F-1: Meeting summary table

date/frequency	type	Key agenda items	Last Outcome/result
Weekly (Thursdays)	Supervisor meeting	Milestone reviews, design feedback and progress on reporting periods and deliverables	Preliminary report and presentations’ for the final repor are approved
bi-weekly	Experiment	Testings, Iterations Changes in tests	Test results and design changes recorded. See section 9
monthly	Team meeting	Progress updates, report writing, general discussion	Task distribution discussed and assigned, Gantt chart updated to up to date, project plan adjustments agreements

Table F-2: Version Control

Iteration /version	Workflow	Goal	result	changes	evidence
1 12.02	0. Set reference point and make a grid 1. Boot ADP-1(router) and RX	Record different rssi values at	The signal does not propagate further than 2 meters	New router was acquired	EV-F01

	AP+RPI-1 (raspberry pi and alpha network) 2. Connect ADP-1 to AP+RPI-1, measure and write down the distance and the dBm value 4. Move AP+RPI-1 to different coordinates and repeat measurement	different point			
2 19.02	0. Set reference point and make a grid 1. Boot ADP-1(router) and RX AP+RPI-1 (raspberry pi and alpha network) 2. Connect ADP-1 to AP+RPI-1, measure and write down the distance and the dBm value 3. Holding AP+RPI-1, walk on a trajectory. 3 trials: Square path 1 Square path 2 Straight path Method: continuous (check 5.2 - concept 1)	Find a definite relationship between distance and rssi	The pattern is irregular and not logical The readings are inconsistent and unstable	Increase sampling distance (increase grid cell size) Try more reading-position synchronization approaches	EV-F02
3 14.03	0. Set reference point and make a grid 1. Boot ADP-1(router) and RX AP+RPI-1 (raspberry pi and alpha network) 2. Connect ADP-1 to AP+RPI-1, measure	Develop a workflow Gather data and estimate a location	n: 2.0 rssi0: -26.39730095455916 mode of localization: Cumulative accuracy ratio: 0.52	Use walk-and-stop Leave 2 meters from walls on a testing field	EV-F03

	and write down the distance and the dBm value 3. Holding AP+RPI-1, walk on a trajectory. 6 trials: 4 zigzag 1 square 1 line Method: continuous, separate sampling, and walk-and-stop (check 5.2 concept 1, 2, 5)	satisfying req1, req2, req4, req5 Prepare a repeat trial with the UAV	(req 04 not satisfied) target: [8.80, 1.80] m predicted (last): [7.60, 1.40] m squared error (last): 1.60 m² (req 05 not satisfied)		
3 29.03	0. Set reference point and make a grid 1. Boot ADP-1(router) and RX AP+RPI-1 (raspberry pi and alpha network) 2. Connect ADP-1 to AP+RPI-1, measure and write down the distance and the dBm value 3. Holding AP+RPI-1, walk on a trajectory. Method: walk-and-stop	Develop a workflow Gather data and estimate a location satisfying req1, req2, req4, req5 Prepare a repeat trial with the UAV	Failure due to low update rate	Find a venue with strong internet connection	EV-F04
4 3.04 ground	0. Set reference point and make a grid 1. Boot ADP-1(router) and RX AP+RPI-1 (raspberry pi and alpha network) 2. Connect ADP-1 to AP+RPI-1, measure and write down the	Satisfy REQ-5	High-interference corrupted the values	Re-iteration of the ground experiment was done in a new venue and with stricter timing control	EV-F05

	distance and the dBm value 3. Holding AP+RPI-1, walk on a trajectory. 7 trials: 4 square 3 zigzag Method: walk-and-stop 4. Mount AP+RPI-1 onto UAV-1 securely 5. Ensure safety requirements are satisfied 6. Pilot uav over the trajectory. 4 trials: 4 square				
5 4.04 air	Method: walk-and-stop 4. Mount AP+RPI-1 onto UAV-1 securely 5. Ensure safety requirements are satisfied 6. Pilot UAV over the trajectory. 4 trials: 4 square	Satisfy REQ-6	The requirement wasn't satisfied	Stick to the ground based experiment until better data collection using the UAV will be made possible	EV-F06