

Received Signal Strength Indicator Based Local Positioning System

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1. Introduction

1.1 Project Description

1.1.1 Background

In this era of automation, the capacity to precisely navigate through various environments predicts the success of the system. The positioning systems are designed to fit numerous purposes, use cases, and environments and facilitate determining the location and the direction of a system or individuals. Obtaining real-time positioning information is crucial for various instances, including navigation of ships and airplanes, situational management in emergency services, agricultural monitoring, military applications, industrial automation robotics, etc. Different positioning systems provide varying levels of accuracy and precision based on technology, algorithms, and the environment in which they operate. Most common systems used in smartphones for general purposes have an accuracy of approximately 5 meters [1]. While this accuracy is generally sufficient for everyday use and navigation, some cases, such as autonomous surveillance and navigation, require a more enhanced degree of accuracy. Furthermore, precision and accuracy rely heavily on the operating environment to the extent that some positioning systems might not function efficiently and properly in specific environments. For this reason, different types of positioning systems are used.

Those can be classified into two main categories: global and local positioning systems. Global positioning systems (GPS) utilize satellites to provide worldwide coverage and relatively accurate location information. On the contrary, local positioning systems (LPS) use short-range signaling nodes to obtain the exact location of systems.

GPS operation principle requires continuous signal reception from at least four GPS satellites. The end-receiver determines its distance from the satellites using the time it took for the signals to travel, hence triangulating and obtaining its position. While GPS provides worldwide coverage, its application can be limited to specific environments. Three significant problems can be identified: weak reception of GPS signals, compromised GPS signal integrity, and restricted positioning accuracy [2].

As mentioned above, undisturbed signal reception is necessary for the operation of GPS; however, the signals cannot fully penetrate water, walls, bridges, or similar obstacles. This makes GPS less, if not minimally efficient, for cases like underground positioning, navigating by huge obstacles, or in subsurface areas.

The location is obtained in relation to the satellites from which the system receives signals. This means incorrect satellite position, distance measurement, or malicious signal manipulation would result in inaccurate positioning. Sometimes, the incorrect signals might not be detected, hence, the system will be unaware of the faulty positioning calculation.

The signals might also be impacted by their path environment. As the signals pass through the atmosphere, their speed is affected; additionally, measurement noises or clock errors on the receiver end lead to possible calculation errors [2]. All problems mentioned are critical issues if high accuracy of the positioning is required. Continuous monitoring and signal correction are necessary to reduce the possible errors, but the accuracy would still be limited.

Compared to GPS, LPS can operate in limited geographical areas and have operation ranges depending on the system specifications. Technologies and algorithms utilized by LPS are more particular to the operational environment and can be altered accordingly to meet certain

needs. These systems can function based on Wi-Fi triangulation, Bluetooth, radio signals' time-of-flight measurement algorithms, infrared sensors, or a combination of different technologies. The short-range signaling specification of LPS allows to obtain the more accurate and precise positioning information, enabling systems to alternate their precision based on specific needs (i.e., power consumption, system limitation, use cases, etc.). LPS outperforms global systems in environments where GPS is denied, or its accuracy and precision are highly limited.

Compared to various types of LPS, utilizing Software-Defined Radio (SDR) technology gives the advantage of having adaptable and flexible solutions. SDR technology provides software-based algorithms and configurations, allowing it to process diverse signals and operate in different environments and conditions. This advantage enables obtaining better and more accurate positioning information and tailoring algorithms, protocols, and solutions to suit particular applications and needs. Prototyping and testing are relatively more straightforward and less complicated due to their adaptiveness, providing a great environment to improve and upgrade the algorithms without changing the hardware specifications and avoiding additional costs.

In the scope of positioning systems satisfying various environmental specifications and applications, the principles of Time of Arrival (TOA) and Received Signal Strength Indicator (RSSI) form the basis of many techniques for determining accurate location information.

Obtaining positioning information using the technique TOA involves determining the position of a target in relation to known base stations. TOA measurements rely on the principle that the time taken by a signal to travel between two points is directly linked to the distance between those points [3]. TOA-based positioning methods also include techniques such as Time

Difference of Arrival (TDOA) and Time Sum of Arrival (TSOA), although the latter is less commonly used.

In Received Signal Strength Indicator (RSSI)-based localization, again, multiple base nodes are used to locate a target node through triangulation. However, unlike TOA, RSSI estimation relies on measuring the strength of the received signal to find the distance traveled by the signal [3]. For a coplanar scenario, assuming known transmission strength and channel characteristics, at least three base nodes are typically required for effective triangulation. With proper configurations and calibration, high precision (0-50 meters) of localization can be achieved [3].

Earlier positioning applications, particularly those emphasizing high accuracy over system simplicity, favored methods like TDOA/TOA or Angle of Arrival (AOA) measurements, especially in scenarios involving a limited number of receivers or sensor arrays. However, the tendency has shifted with the increased number of wireless devices and networks, leading to more observation points closer to the target. This process has raised the need to adopt RSS-based approaches, especially in indoor or non-line-of-sight (NLOS) environments.

Despite the generally lower accuracy with fewer nodes, RSSI-based localization stands out as a cost-effective and straightforward solution. RSS information, already integral to many wireless standards, serves various fundamental radio functions and can be used in location systems without additional hardware or modifications. This simplicity makes RSSI a feasible method, especially in scenarios where it may be the only available ranging information due to environmental challenges or specific applications, such as surveillance or security.

RSSI based local positioning systems rely heavily on accurate distance measurements for precise positioning. While considering the constraints of traditional RSSI based algorithms, which often rely on standard parameters that are sensitive to environmental influences, this project focuses on refining these distance estimation processes. Most implementations of this systems traditionally focus more on enhancing positioning accuracy after distance calculation are made. This approach often overlooks the critical role of initial distance estimation. However, this project prioritizes improvements in distance estimation to ensure more accurate positioning from the onset, by implementations of advanced filtering algorithms and appropriate signal propagation methods.

1.1.2 Assumptions and Constraints

As the project aims to achieve high precision, various factors impacting RSSI measurements should be considered. Those can be signal attenuation changes due to obstacles, signal reflections, or interferences from neighboring devices. To enhance accuracy, the number of base stations can be increased. The utilization of more stations will allow to refine location estimates, enhancing the system's precision within the 0-50 meter range. However, while additional stations contribute to improved accuracy, optimizing their utilization and placement requires careful consideration.

Similarly, environmental variations pose significant challenges that can lead to potential inaccuracies. Factors such as signal interference from natural or artificial sources and signal degradation due to atmospheric conditions contribute to measurement inconsistencies. Incorporating corrective techniques, such as using a minimum of two stations for initial calibration and environmental adaptations, aid in correcting these inconsistencies. These corrections are essential, yet in some cases, might not be necessary. The relative nature of

distance calculations allows to skip the corrections if all stations are positioned closer to each other and are affected by the same environmental conditions.

It is essential to acknowledge that achieving the best implementation and final concept will require prolonged development time because of the complexity of SDR implementations.

This development phase is the initial proof of concept, demonstrating the feasibility and foundational aspects of the project. However, it's important to note that this is the initial phase. Further work and in-depth development with a more extensive timeframe will be needed past this proof-of-concept stage to achieve the comprehensive final version of the project.

1.2 Overview of the Envisioned System

1.2.1 Overview

The proposed LPS is built based on the Adalm-Pluto module, implementing distance measurement between nodes. The Adalm-Pluto module, developed by Analog Devices, is a compact and cost-effective Software-Defined Radio solution. With its wide frequency coverage and customizable features, it's an accessible platform for experimenting with wireless communication protocols and signal processing techniques. The system mainly utilizes the capabilities of the Adalm-Pluto module's Software-Defined Radio to accurately measure the distance between two points and obtain location positioning information. The project's objectives are the advancement of accuracy and precision in distance measurement using the RSSI technique within the SDR framework.

Moreover, the system's positioning methodology is based on a network consisting of a minimum of three nodes. By employing multiple nodes strategically, the system aims to triangulate positions accurately, ensuring dependable positioning capabilities, especially in

dynamic and complex environments. This methodology is essential for the system's overall performance, especially in specialized applications such as drone surveillance in NLOS environments.

In order to improve the distance measurement results, this project focuses on several crucial aspects: the modulation type of the signal, the selection of antennas, the operating frequency, and the application of post-measurement filtering techniques. Each of these play an important role in enhancing the accuracy and reliability of distance estimations. It is important to note that the platform provided by Adalm-Pluto, specifically the use of SDR, allows seamless integration of different changes based on different needs. This project provides the basis for improved distance estimation; however, most parameters can be adjusted accordingly to meet the range, data rate, power consumption, security and much more specific requirements. In the scope of this project a simple GUI is provided, to implement changes, tackle parameters and test a system based on integration requirements.

1.2.2 System Scope

The primary objective of the LPS is to precisely determine the distance between two nodes within the system, which may serve as the basis for various platforms, including drones, automated vehicles, indoor positioning systems etc. The system should be incorporated into specific setups and configured appropriately. The project provides the key functions and operational modes for obtaining appropriate positioning information.

The current stage of the project primarily emphasizes distance measurement, with plans for future development to accommodate synchronization, refined communication protocols, and additional functionalities between the nodes. This focus on distance measurements aligns with

the project's initial objective to set the foundation and groundwork for advancement in system capabilities and enhancement in the future.

This project intentionally excludes physical housing or mounting specifications, focusing solely on the operational and technical aspects. The mounting specifications should be tailored and adjusted based on the use cases and setups into which LPS will be integrated.

2. Documents

2.1 Applicable Documents

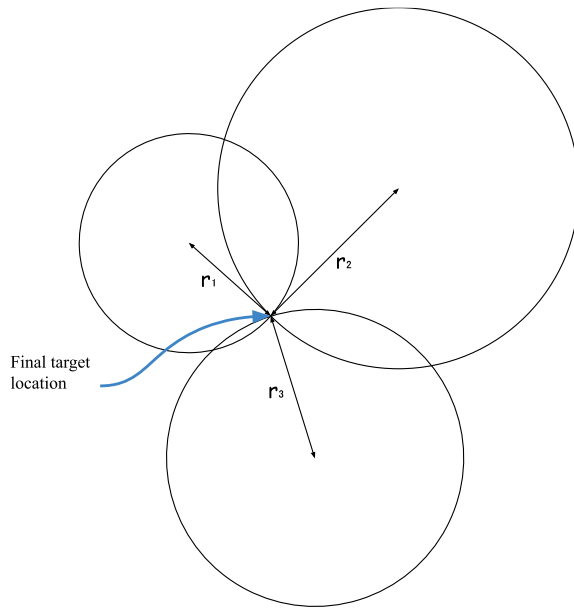
1. **Adalm-Pluto Schematic:** This schematic provides detailed insights into the hardware layout and components of the Adalm-Pluto module [4]. It serves as a fundamental reference for understanding the module's architecture, aiding in the development and integration of the system.
2. **AD9363 Datasheet:** This datasheet contains comprehensive technical information about the AD9363 chip, detailing its functionalities, specifications, and electrical characteristics [5]. It serves as a critical resource for understanding the capabilities and limitations of the chip integrated within the Adalm-Pluto module.
3. **"Handbook of Position Location: Theory, Practice, and Advances":** This book serves as a reference for implementing RSSI techniques, algorithms, and descriptions relevant to the system's positioning methodology [3]. Specific sections or algorithms related to RSSI-based positioning will be utilized as guidance for the system's design and implementation.

2.2 Reference Documents

Trilateration is a mathematical technique used to determine the positions of target devices based on the distances from multiple known static nodes. Typically, trilateration discusses the cases involving three nodes, and multilateration is used in the context of a system with more than three nodes. This technique is fundamental to many positioning systems, including GPS, as it provides a reliable method for calculating the target's location based on measured distances.

In the context of this project and positioning system, trilateration plays an important role in accurate positioning within the operational area coverage created by the nodes. The reference documents discussed in this section provide comprehensive insights about the algorithms, improved methods of trilateration and mathematical methods to optimize the process for real-world applications.

When considering trilateration alongside the ideal and simple case is considered the real world, non-ideal implementation. In the ideal scenario, trilateration involves non-collinear nodes that transmit signals to a receiver, which has precise information about their positions. These distances, if treated as radii, create circles, which, in ideal case, intersect at exactly one point, marking the target's exact location. However, in real-world scenarios, especially considering obstacles and signal interference, the distance measurement is not very precise, hence the circles don't intersect so perfectly.



In practice, these inaccuracies result in the circles intersecting in a way that forms a triangle (or other shapes if more nodes are involved). This happens because the measured distances are not perfectly accurate, which causes the circles to overlap incorrectly. To address this issue and estimate the position of the target, in cases like this a simple approach is used: to calculate the centroid of the triangle formed by the intersections of the circles. The centroid of a triangle is the point where the medians of the triangle intersect. It is calculated as the average position of all the vertices of the triangle, providing a balance point that can be considered the estimated location of the target.

3. Description of the Envisioned System

3.1 Needs, Goals and Objectives of Envisioned System

The envisioned system strives for adaptability, designed as a versatile LPS that can seamlessly integrate into various systems and setups without being confined to any specific application or use case.

Initially, this project aimed to extend and optimize the implementation of LPS developed by Instigate Robotics while reusing the main algorithms. This approach was chosen because of identified needs that arose during the system's operation, such as the need for hardware implementation of Fast Fourier Transform (FFT) instead of software to achieve faster implementation. It was envisioned that these modifications would optimize and improve the implementation of their system. The model was intended to be used in drones surveying over a specified area in a sea. This allowed them to use positioning techniques without considering the factor of Line of Sight (LOS).

However, after intensive research and evaluation, a strategic shift in the project's direction occurred. Instead of pursuing optimization exclusively, a decision was made to implement a new positioning technique based on RSSI, leaving behind the original plan to enhance the initial system. The main optimization of it was based on the hardware implementation of FFT, however, this task faced constraints as the Adalm-Pluto architecture used extensive resources of Digital Signal Processing (DSP) blocks, obstructing the hardware implementation plan of FFT [6, 4]. Moreover, its operation was limited by its reliance on continuous unobstructed Line of Sight (LOS) due to its base positioning technique (TOA). The

newly adopted methodology addresses these challenges by offering a less complex yet comparatively accurate system.

The project's revised goal centers on integrating an RSSI-based positioning technique. This strategic shift aims to utilize RSSI advantages over TOA, enhancing accuracy and precision without pursuing FFT optimization and avoiding the requirement for continuous LOS, thus overcoming the significant operational limitations of the initial system.

One of the objectives of the system is to use Adalm-Pluto module's SDR capabilities, to increase the accuracy and precision in distance measurements through the implementation of the RSSI technique within the SDR framework. Leveraging the flexibility of SDR allows to explore various characteristics such as modulation types, configurations, and signal processing techniques. This adaptability gives the freedom to experiment with different parameters, optimizing the system for improved in certain environments.

The system's primary objective remains to precisely determine distances between nodes, offering flexibility for integration into various platforms and setups.

3.2 Overview of System and Key Elements

The LPS is designed as a versatile framework including distinct functional elements collaborating to achieve precise node-to-node distance determination. These components include the Adalm-Pluto module with Software-Defined Radio capabilities, data processing units, signal transmission modules, and user interfaces. The system carries out seamless communication, data processing, and user interaction while remaining implementation-agnostic.

The platform is designed to serve to diverse user base, allowing users to experiment and customize the system according to their specific requirements. Users, whether looking for

accurate distance measurement information or curious to explore different parameters and tackle with the range of operation of the system, can use the platform to tailor parameters. This approach allows users to explore and adapt the system to meet their diverse needs.

The primary objective of the system revolves around accurate distance measurement between nodes, using the RSSI technique within the SDR framework. RSSI provides the signal strength information, enabling precise distance estimation and minimizing dependencies on continuous LOS scenarios. In the designed RSSI based system, the process begins with the transmission of a signal from one node to the target device. Once the receiving node is identified with a custom message, RSSI measurements are taken to determine the signal strength. To enhance the accuracy of the measurement, after it is done, a Kalman filter is applied. This filtering method effectively reduces the noise inherent in RSSI data, leading to better and more precise distance calculations. The application of the Kalman filter is essential in reducing the effects of variability introduced by various environmental factors and possible signal fluctuations, ensuring that the distance calculations made based on RSSI measurements are reliable.

To further refine the system and allow to perform real-time analysis and customization, a graphical user interface (GUI) is provided. The GUI serves as a simple platform for visualizing the received data, including the raw RSSI values and the outcomes post Kalman filter application. Users can alternate the modes, configurations, plot the data dynamically, observe the effects of the applied filter and adjust the parameters for required optimization. The default configuration set is the optimized parameters for enhanced distance measurement precision enquired during the development of this project.

When using multiple nodes, the target device can operate in a mode to function as an LPS. While this feature is for demonstration of its potential for expanded functionality, it's important to note that LPS is in a prototype stage. The synchronization, communication establishment and other critical aspects are yet to be optimized for widespread use. However, this prototype shows the enhanced distance measurements are achievable within the system. This demonstration highlights the progress in refined distance measurements precision.

3.3 Interfaces

3.3.1 Radio communication

The communication between the nodes is supported by the SDR capabilities of Adalm-Pluto module. The modules enable to transmit and receive digital signals from one node to another using signal modulation. In the case of SDR, modulation is the process of converting the digital carrier signal into analog signals for optimized transmission. During this process the digital data is encoded in a signal with specific alternating characteristics such as amplitude, frequency, and phase. For example, if we utilized a simple case of frequency modulation, in the modulated data 0s would be distinguished with a frequency of f_1 and 1s with a frequency of f_2 . Most common types of digital modulations are Amplitude shift keying (ASK), Frequency shift keying (FSK) and Phase shift keying (PSK).

Two things were considered when choosing the modulation type sensitivity to noise and strength variations due to changes in transmitted message. To ensure stable communication between the nodes ASK was not considered, as it can be susceptible to interference in noisy environments or over long distances. Additionally, as we rely on RSSI measurements for distance estimations, different messages would alternate the signal strength due to ASK's nature. Both PSK and FSK were suitable options, however with experiments it was decided to go ahead

with FSK modulation. PSK modulated signal had limited range of operation and required consistent configuration adjustment to operate at different distances. When using PSK (in the experiments BPSK and QPSK were used) it is important to note that data integrity depends on the stability of the phase of the signal. In a scenario when the phase changes, even from environmental factors or hardware problems, the data being transmitted will be heavily influenced. As the distance was increased these changes became more apparent, and the receiver struggled to differentiate between the phases that represented different data bits, which led to inconsistent communication.

Unlike ASK and PSK, FSK is more resilient to amplitude related noises or phase disturbances in environments where signals can be affected because of obstacles, interferences, or varying distances. Moreover, FSK modulation is simpler to demodulate, compared to PSK when conditions are not so ideal. For these reasons, FSK modulation was preferred, and is the main cornerstone for node-to-node communication.

For this project, operational range is chosen within the 433 MHz frequency band, particularly connected to its legal allocation for unlicensed use in Armenia. This frequency is part of the Industrial, Scientific, and Medical (ISM) radio bands, which are widely recognized to be used for short-range communications, and do not require licensing, which simplifies the deployment and operational legalities for the project.

Along with this, the 433 MHz band penetrates obstacles better compared to higher frequencies. Lower frequency waves have longer wavelengths, allowing them to penetrate various materials more effectively and undergo less attenuation over longer distances. Higher frequencies, on the other hand, are more likely to be absorbed or reflected by obstacles and cover shorter distances. Lower frequency signals experience less attenuation.

Furthermore, GPS systems operate at much higher frequencies, at more than 1227.6 MHz. These frequencies are significantly higher than 433 MHz band, which leaves the system outside the more commonly jammed or interfered frequency ranges. In scenarios where GPS signals are denied or especially jammed, the use of 433 MHz band for local positioning system will support an additional layer of security. Operating on lower frequencies minimizes the system's vulnerability to the same jamming techniques that might be directed at GPS. This choice increases the reliability of the positioning system and enhances its resilience under diverse and adverse conditions.

In the project were used omnidirectional antennas, which are specific to project's application needs. Omnidirectional antennas radiate and receive signal in all horizontal directions almost equally. This makes them ideal for scenarios where the direction of the incoming signal direction is not constant or can't be predicted. This feature is beneficial for the system, as in dynamic environments the target is moving, and the system must interact seamlessly with all nodes without needing to reorient the antenna.

In the system, each node initiates a connection by sending a signal that includes a specific message to identify itself. This is important as the target needs to distinguish each node within the network to compute its position, based on the received signal.

Overall, the radio communication interface is tailored to support continuous communication between the nodes, even in dynamic or obstructed environments.

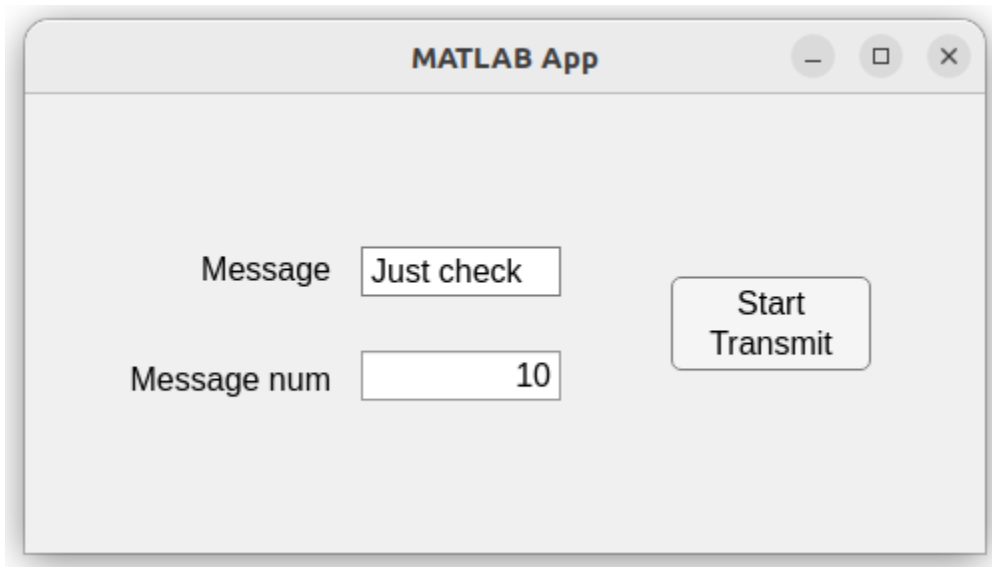
3.3.2 User interface

The system includes two distinct graphical user interfaces (GUIs) developed in MATLAB, that are designed to manage the operations on both the transmitter and receiver sides.

To establish a connection with Adalm-Pluto module a simple connection using its USB port is made. The first GUI is used for experimenting and obtaining estimated distance measurements, and the second is tailored for target positioning. Both interfaces allow the users to customize settings, initiate the process, and visualize results effectively, giving the platform for both experimentation and practical deployment of the positioning system.

3.3.2.1 Experimental and Measurement Interface

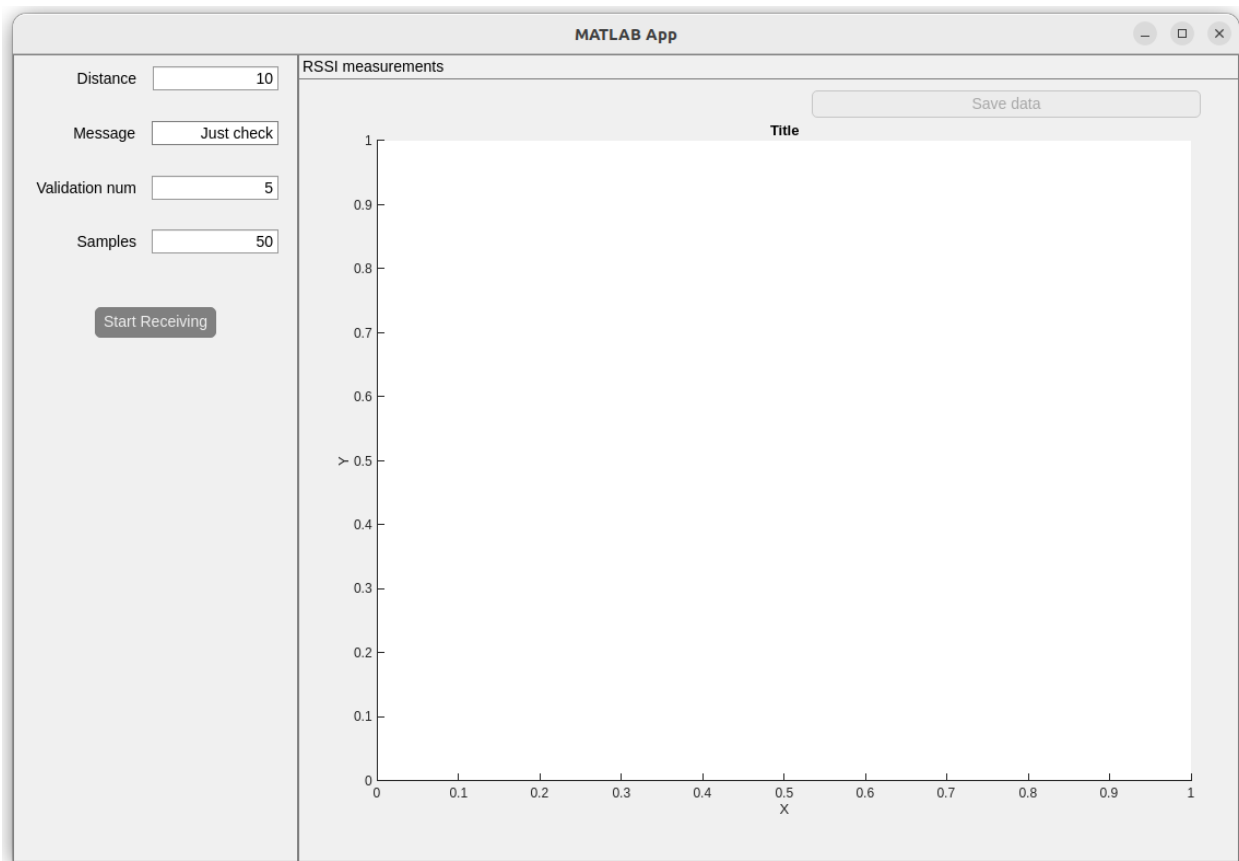
Transmitter interface: The transmitter GUI supports the initiation of the transmission process from the node to the target. Users can set custom message for identification, select the number of messages to be sent, and choose the operating frequency. The initial values are preset for easy use and compatibility with the receiver.



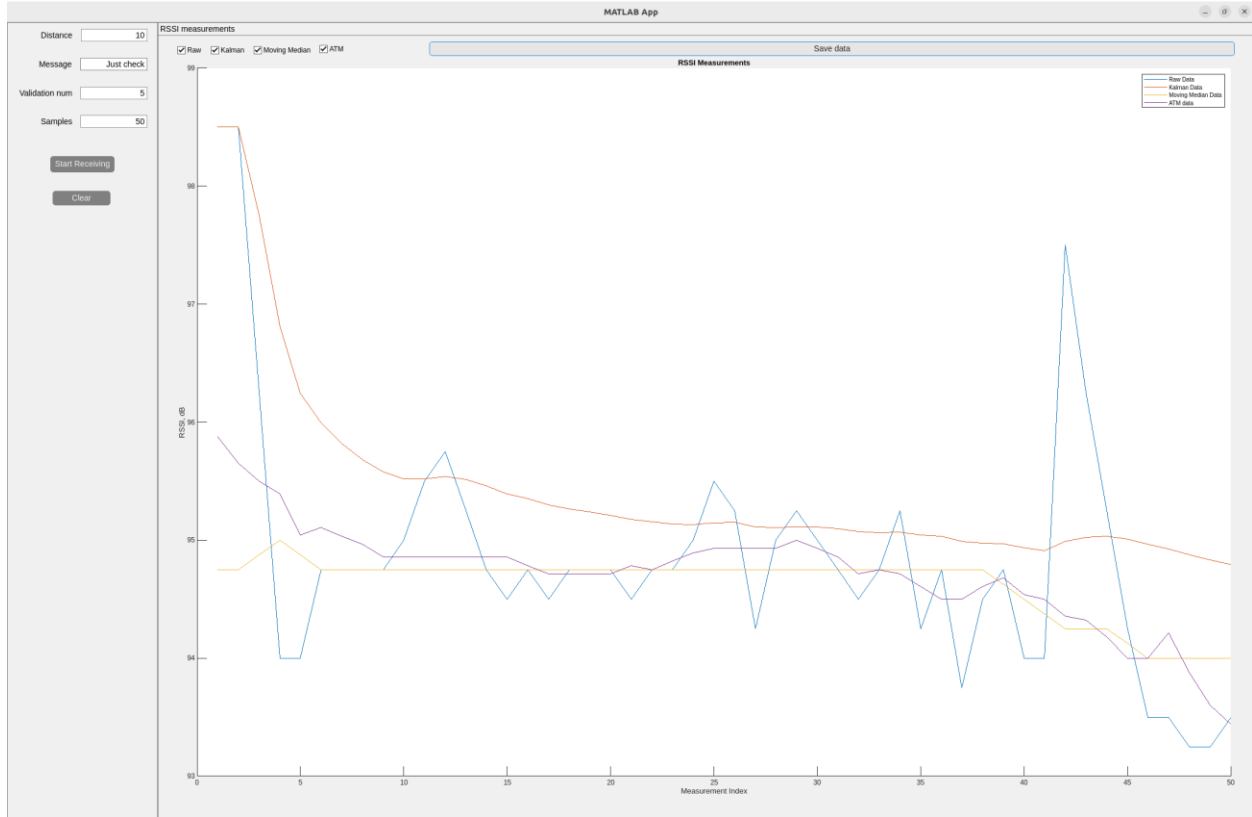
Picture 1: Transmitter GUI

Receiver interface: On the receiver side the GUI is designed to handle the reception process. Users can set the custom message to wait from the transmitter, number of messages to receive to confirm the identity of the node, the operating frequency and specify the number of

measurements to make. The default values are compatible with the transmitter. As the reception of the signal is done, visualization of the signal is provided. The raw RSSI values are plotted, along with integrated filters: moving median, alpha-trimmed mean and Kalman. Users can toggle these filters on or off for better analysis and save both the values and the plot. As the user conducts two tests at two different distances, the system also calculates the estimated distance based on these measurements and displays the estimation result.



Picture 2: Receiver GUI



Picture 3: Receiver GUI after measurements

3.3.2.2 Positioning Interface

Transmitter interface: The transmitter's side is made just for initiating or halting the process with a simple button and setting the identification number of the node (1, 2 ... n). In case of positioning, custom transmission settings are not accepted.

Receiver interface: The receiver's positioning GUI allows to configure the number of nodes involved in the positioning process and set their respective positions. Users can initiate the measurement process with options to adjust settings as necessary. When the measurements and calculations are complete, the system displays the estimated position of the nodes. This interface

aims to provide a clear and intuitive visualization of the nodes' locations based on the optimized algorithm.

3.4 Modes of Operation

The system operates in two modes, each for different phases: Distance Measurement Mode for testing, experimentation, and calibration purposes, and the Positioning Mode for operational deployment.

3.4.1 Distance Measurement Mode

This mode is essential for development and testing, which allows to do adjustments of settings such as frequency selection, custom message configuration and the application of various filters to analyze their effect in different environments.

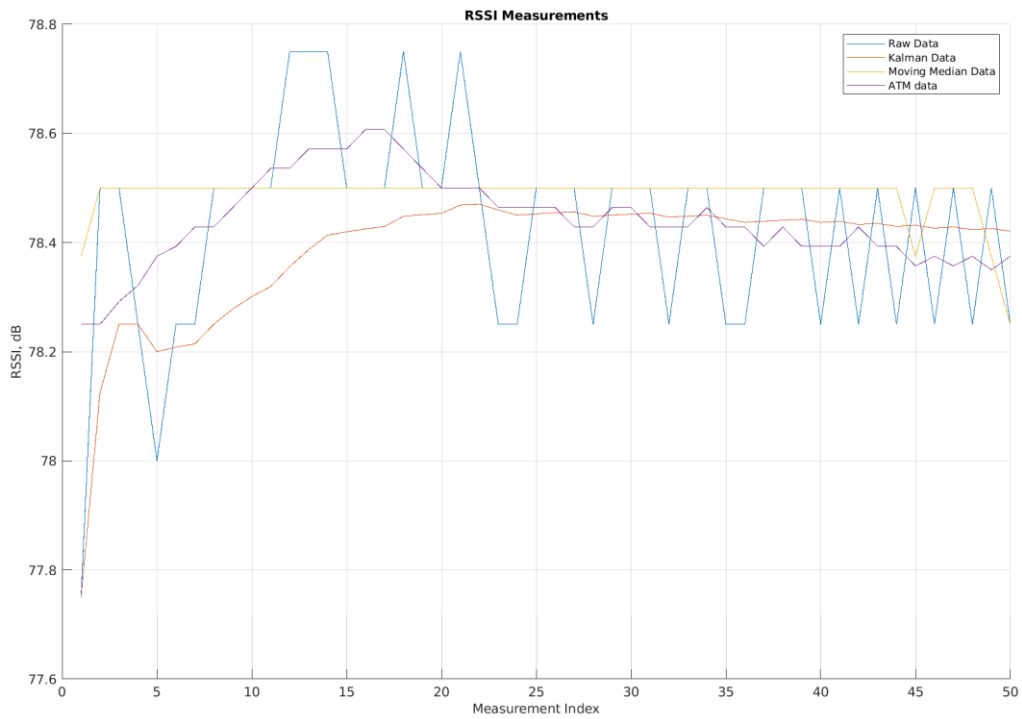
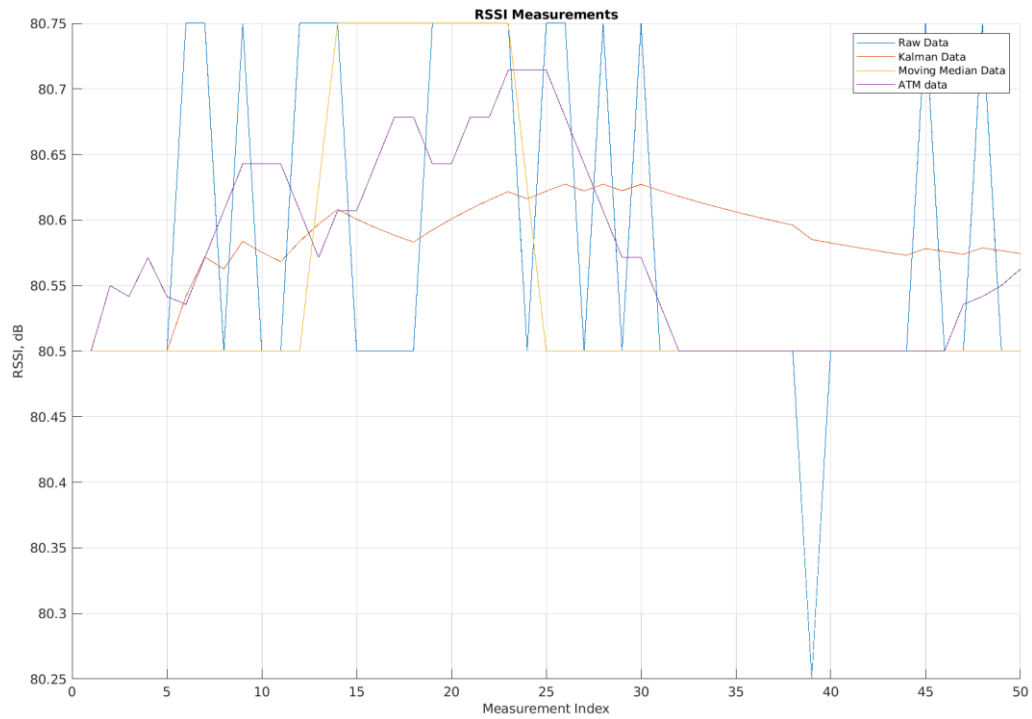
3.4.2 Positioning Mode

In the operational mode the system has simpler settings to ensure optimal performance in different environments. It includes fixed operational frequency range, predefined message setting compatible with all nodes to ensure easy integration.

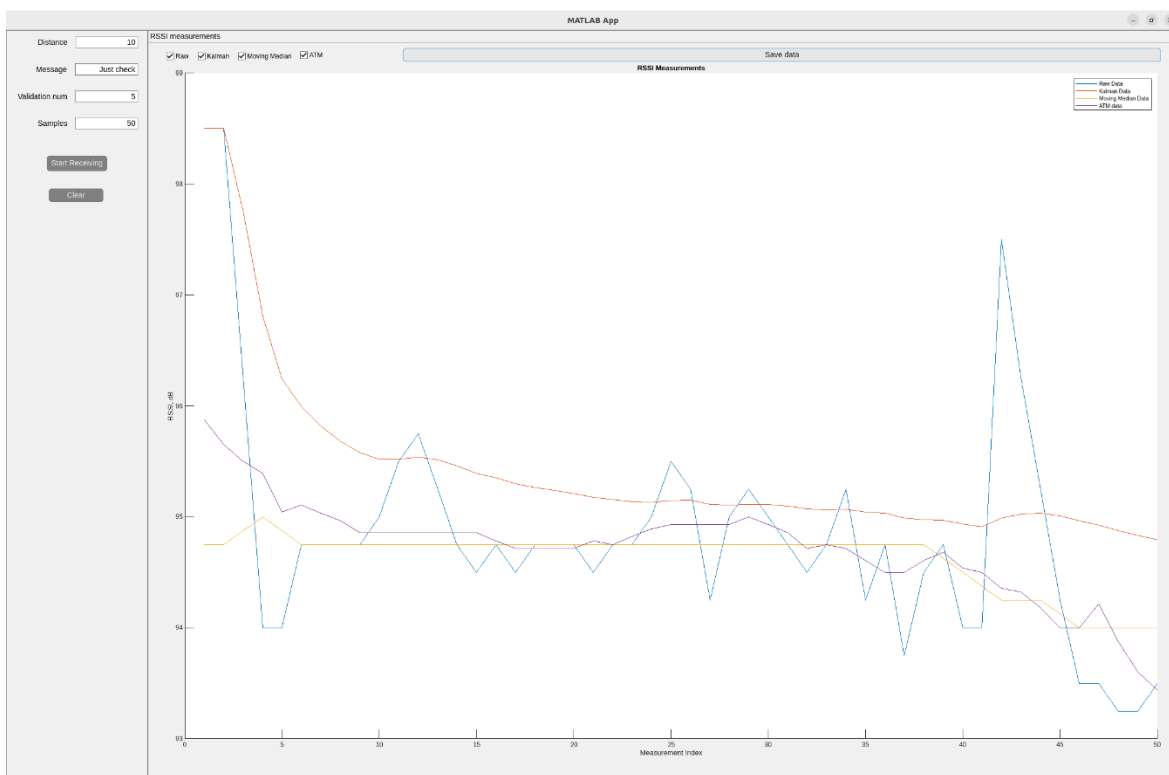
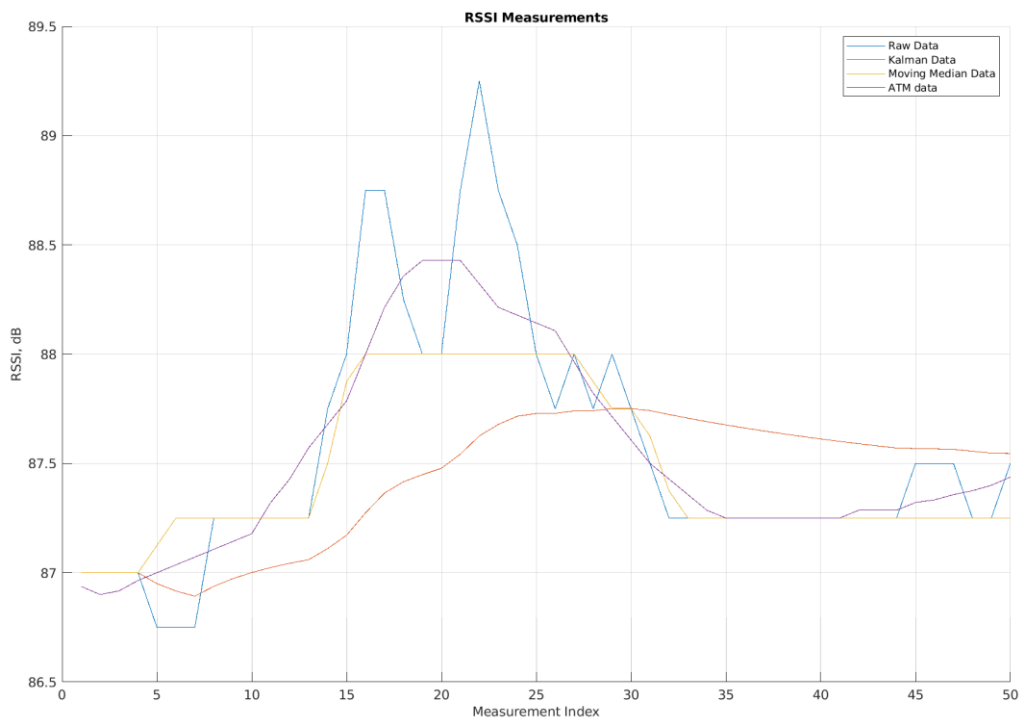
The system operates at 433 MHz, specifically chosen for its effectiveness in better obstacle penetration and less susceptibility to interference. Both are important factors to ensure reliable communication in varied environments. Messages for identification are preset to ensure compatibility and easy identification among all nodes. This setup minimizes configuration mismatches and eases the use. In the system the focus is on utilizing time-division multiple access (TDMA) for node distinction. Each node transmits data in its designated time slot, reducing the likelihood of signal collision and improving the system organization.

This method contrasts with frequency-division multiple access (FDMA) method, which allocates distinct frequency bands to different nodes. While FDMA can be effective, most often it introduces complexity in tuning and managing frequency allocations, especially in environments where spectrum restrictions might apply, or interference is a problem.

The specific use of the Kalman filter in the Positioning Mode is based on the experimental data obtained during the project implementation. It showed better and more consistent results in different conditions and proved to handle variable RSSI values effectively. This filter stands out in estimating states from unpredictable data, particularly useful in dynamic environments where signal integrity may be compromised. The Kalman filter continuously updates and corrects the system's estimates, which provides a higher level of accuracy, consistency, and real-time responsiveness, important for the precision required in positioning systems.



Picture 4: Measurement results in steady enviornment



Picture 5: Measurement results in noisy environment

With the focus on these specific methods, the system ensures optimized performance during both the testing phase and operational deployment. The integration of TDMA and the Kalman filter ensures the system is reliable and efficient.

4. Physical Environment

The operational conditions envisioned for the proposed LPS proof of concept primarily align with normal atmospheric parameters, including temperature variations and ambient humidity levels. Notably, owing to the current absence of protective housing—a characteristic inherent to the proof of concept nature—the system's resilience to extreme weather conditions such as rain or snow remains a consideration for future iterations. This aspect highlights the ongoing developmental phase of the project, where the priority lies in demonstrating core technical functionalities rather than physical protection.

5. Support environment

At this phase, the system needs physical updates. These updates involve establishing connections and installing new firmware to ensure operational efficiency and updated functionalities.

Appendix A: Acronyms

GPS – *Global Positioning System*

LPS – *Local Positioning System*

SDR – *Software Defined Radio*

TOA – *Time of Arrival*

RSSI – *Received Signal Strength Indicator*

TDOA – *Time Difference of Arrival*

TSOA – *Time Sum of Arrival*

AOA – *Angle of Arrival*

NLOS – *Non-Line of Sight*

LOS – *Line of Sight*

SoC – *System on Chip*

PL – *Programmable Logic*

PS – *Processing System*

FFT – *Fast Fourie Transform*

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