Shared Access for Family Electrically-Assisted Tricycle – Final Year Engineering Project Report

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5 ISS
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Summary

I. Introduction

This report presents the outcomes of our innovative project, undertaken as part of our final-year studies in the 5th year of the ISS (Innovative Smart Systems) program at INSA. As a team of motivated students, we chose to focus on the integration of Ultra Wideband (UWB) technology into the automotive domain, a field that promises to revolutionize vehicle connectivity, security, and user experience.

Throughout this report, we detail the objectives, methodologies, and results achieved during this project, while highlighting the challenges encountered and the innovative solutions developed.

II. Presentation of the partners

This project was carried out in collaboration with key industry partners, Actia and NXP, as well as with the students from Linköping University in Sweden.

Actia, one of our key partners, is a global leader in automotive electronics, specializing in vehicle connectivity and embedded systems. They provided critical guidance on integrating UWB technology into automotive environments. Actia ensured that our work aligned with industry standards and facilitated access to real-world scenarios for testing and validation. The commitment of Pierre Gruyer, Innovation Program Manager, to innovation and support played a vital role in helping us achieve the project's objectives.

NXP, another key partner in this project, is a leading semiconductor manufacturer renowned for its expertise in wireless communication and embedded systems. NXP provided us with their state-of-the-art UWB development boards, which formed the foundation of our work on this project. We were in contact with Youssef Houiti, System Application Engineer.

In addition to Actia and NXP, we collaborated with a team of students from Linköping University in Sweden. This international partnership fostered an exchange of ideas, methodologies, and diverse perspectives, enriching the development process. The collaboration allowed us to address complex challenges with a multidisciplinary approach and highlighted the value of teamwork across borders in achieving innovative outcomes.

Throughout the project, we were also supported by Thierry Monteil, professor and researcher at INSA Toulouse, who provided guidance. His involvement played a key role in transforming our ideas into practical and innovative solutions.

III. The project and its main objectives

The primary objective of this project was to characterize a positioning system using Ultra Wideband (UWB) technology for vehicle access and to conduct extensive testing to evaluate its performance.

Our project was structured around the following main objectives:

1. Characterization of UWB-Based Positioning Systems:

The core goal was to analyze and define the capabilities of UWB technology for determining precise location data. This included examining parameters such as accuracy, range, and response time to ensure the system's suitability for automotive applications like keyless entry and proximity-based control.

2. Testing and Validation in Real-World Scenarios:

Conducting comprehensive tests to assess the system's performance under various conditions. These tests were designed to simulate real-life scenarios, including environmental challenges such as signal interference.

IV. UWB (Ultra Wideband) technology

Ultra-Wideband (UWB) is a wireless communication technology that operates across a wide frequency spectrum, typically ranging from 3.1 GHz to 10.6 GHz. Unlike traditional technologies such as Bluetooth or Wi-Fi, which use narrowband signals, UWB transmits short pulses across a broad range of frequencies. This transmission method offers unique advantages, particularly in terms of precision, reliability, and security.

The distinctive characteristics of UWB include:

- **High Precision**: UWB can measure distances with centimeter-level accuracy through Time of Flight (ToF) measurement, making it an ideal technology for applications requiring precise localization.

- **Low Interference**: Due to its wide frequency band and low spectral power density, UWB is less susceptible to interference from other wireless technologies, ensuring reliable communication in congested environments.

- **High Data Rates**: The ability to transmit data at high rates makes UWB suitable for applications requiring fast and large data exchanges.

- **Low Power Consumption**: With its low power level, UWB is well-suited for portable and embedded devices.

The table above highlights the performance of major technologies used for distance estimation and localization. Among these, Ultra Wideband (UWB) stands out due to its exceptional accuracy (up to 1 cm) and ultra-low latency (<1 ms). These features make UWB an ideal choice for applications requiring precise and real-time positioning, such as intelligent vehicle access control.

Compared to other technologies, such as Bluetooth or GPS, UWB provides superior localization resolution, particularly in complex or crowded environments. For instance, Bluetooth and Wi-Fi exhibit higher latencies and limited precision, making them less suitable for scenarios demanding rapid and accurate position detection.

Technology	Accuracy	Latency
UWB	1 cm	< 1 ms
Bluetooth	1–5 m	> 3 s
WiFi	5–15 m	> 3 s
RFID	1 m	1 s
GPS	5–20 m	100 ms
5G	10 m	< 1 s

Comparison between technologies for distance estimation and localization

Ultra-Wideband (UWB) technology has emerged as a game-changing solution across various industries due to its unmatched capabilities in precision, reliability, and security. Among its many applications, UWB has shown significant promise in revolutionizing vehicle access systems by enabling intelligent and secure localization.

UWB for Intelligent Vehicle Access

In the automotive sector, UWB enhances the functionality and security of keyless entry systems. Unlike conventional proximity technologies, UWB ensures that vehicles unlock or start only when the legitimate key is detected within an authorized range. This is achieved through the bidirectional exchange of ultra-short radio signals between a connected device, such as a virtual key, and multiple anchors or antennas integrated into the vehicle. By measuring the Time of Flight (ToF) of these signals with centimeter-level accuracy, UWB determines the device’s precise location, enabling secure and seamless access.

Key Advantages of UWB in Vehicle Access

1. **Precision and Security**: With centimeter-level accuracy, UWB ensures that only authorized users can access the vehicle, effectively countering threats like relay attacks by verifying the key's exact location.
2. **Responsiveness**: UWB’s near-zero latency allows instantaneous activation or deactivation of vehicle functions, such as unlocking doors, without delay.
3. **Robustness**: UWB outperforms GPS in enclosed environments, such as underground parking lots, where other technologies struggle due to interference or weak signals.

Objectives of UWB-Enhanced Vehicle Systems

The integration of UWB technology in vehicle access systems enables several advanced features:

- **User Position Triangulation**: Precisely locating the key or connected device relative to the vehicle for accurate control.
- **Obstacle Management**: Ensuring consistent system performance even when physical barriers interfere with signals.
- **Dynamic Scenarios**: Adapting vehicle responses to user movements, such as automatic unlocking or triggering personalized settings.

UWB Technology for Secure and Intelligent Vehicle Access

By exploring these capabilities, UWB offers a compelling foundation for creating innovative, secure, and user-friendly vehicle access systems. Its combination of precision, responsiveness, and robustness positions it as a leading technology in modern automotive solutions and beyond.

V. Organisation

Sprints:

In week 40, we visited ACTIA, where we had the opportunity to meet the project team, attend a project presentation by an NXP engineer that featured a live demonstration, and receive a detailed explanation of our roles in the project from Mr. Pierre Gruyer. We also participated in a remote presentation given by Swiss students who had started the project a month earlier, which provided valuable insights into their progress and challenges.

During week 41, we organized a team meeting to address administrative tasks and plan the next steps for the project. In week 42, we attended a comprehensive presentation on UWB technology, which deepened our understanding of its principles and techniques.

Week 43 featured a hackathon where Amine and Baptiste collaborated with student teammates to discuss the project's objectives and strategies. In week 45, we received the WiNo hardware, enabling us to begin initial hardware tests and define specific scenarios for our use case. Week 46 was dedicated to setting up the materials and initiating coding efforts.

In week 47, we continued developing the code to produce the first working version but faced technical challenges. However, in week 48, one of our teachers introduced us to a codebase that provided the critical data needed to calculate the user's position, marking a turning point in our progress.

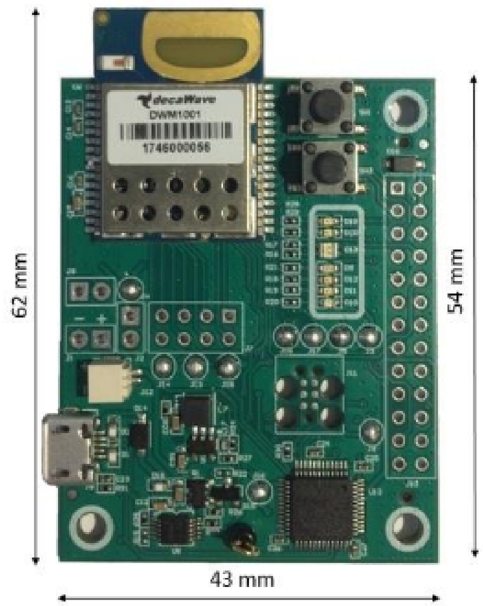
Week 49 saw significant advancements, as we established communication between the boards, implemented the Two-Way Ranging (TWR) algorithm, and successfully obtained position measurements that closely mirrored real-world values.

In week 50, we collaborated with Swedish students during a meeting where they explained their approach to coding the NXP board, allowing us to adapt to the new hardware seamlessly. We also focused on enhancing the precision of distance measurements.

Week 51 was dedicated to implementing triangulation techniques based on Time of Flight (ToF) measurements. Finally, in weeks 52 and 53, we conducted performance tests in a vehicle, evaluating the system's real-world effectiveness and refining it further.

VI. First technical experiments

As said before, unfortunately, we weren't able to get our hands on the NXP system before the end of December. To compensate for this and to try and get a first idea of what Ultra-Wide Band (UWB) ranging systems are, we had the opportunity to work on DWM1001-DEV boards, by Qorvo, thanks to Mr. Monteil who had the idea in the first place.

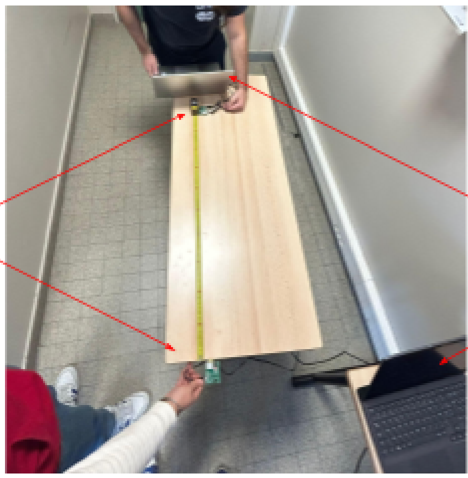


These boards are easily accessible, open to the public and well documented solutions, for anyone who wants to try and set-up their own UWB ranging system, or more.

With this equipment, we were able to implement a Two-Way Ranging (TWR) between two anchors, using Arduino and code from a demonstration which Mrs Rejane Dalcé, researcher at IRIT, gave us access to, after she presented to our whole class the UWB system which, she and her colleagues at Blagnac University Institute of Technology, where she gives classes, have set-up for research and practical works.

This then allowed us to train to run a precision test on the boards, in anticipation for the tests that we knew we were going to run on NXP's system once we would receive it. What we did was to place two anchors (or boards) in front of one another, in direct line of sight, on two tables so they would be levelled. We then proceeded to start an exchange of 200 ranging operations between the anchors, first at a distance of one meter and then at two meters, keeping the anchors static through the process. We hoped that this way we would collect a reasonable amount of samples to determine the UWB TWR's intrinsic precision and accuracy, so that we would be ready to repeat with NXP's boards and would have the possibility to compare the results, to create ourselves a reference. For the rest of this chapter, we will share our results so that you can make an idea for yourself too.

Positioning anchors at 1m

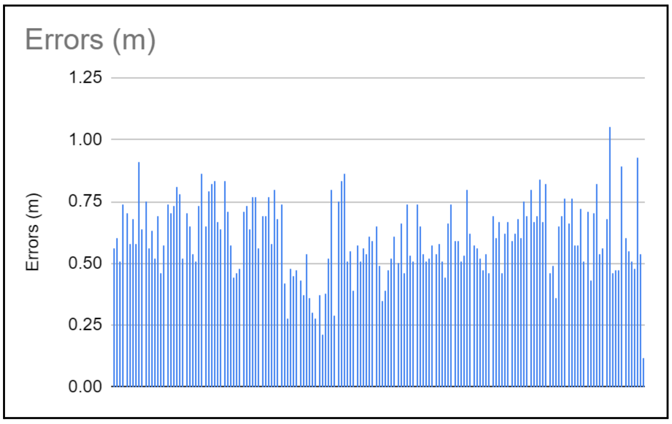


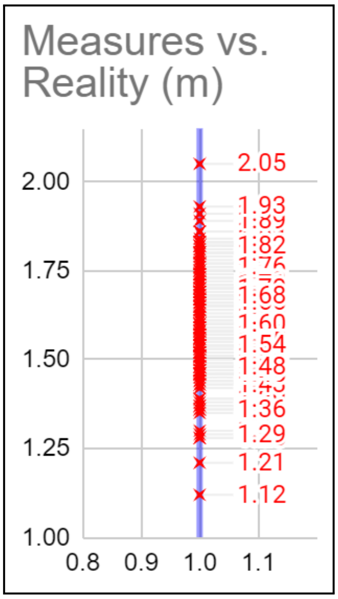
Computers running the code

First tests set-up

Test results at 1-meter distance:

Mean (m)	**1.60**
Standard Deviation (or precision) (m)	**0.1483935533**
Bias (or accuracy) (m)	**0.60**
MAE (m)	**0.6039411765**





Before we start, let us explain exactly the difference between precision and accuracy. The accuracy is the capacity of the system to measure values close to the actual value. On the other hand, precision is the capacity for the system to measure values close to one another, whether or not they are close to the actual value. In this sense, we can consider the graph on the right as a precision graph, showing how all the measurements are spread, on the Y-axis, compared to the target value of 1m, on the X-axis. The errors graph on the left is closer to an accuracy graph, showing how much over the target value each measurement is, on the Y-axis.

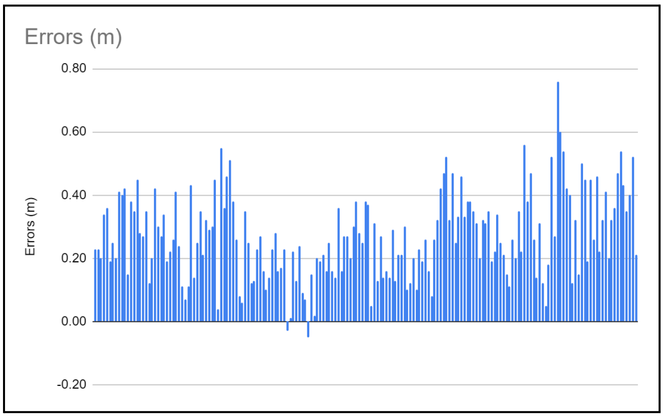
Given this information, from the 200 measurement samples we made, above are the analyses we could extract on the precision and accuracy of two ranging anchors, in a static configuration, at 1 meter. We can see the mean measured value is equal to 1.60m, which means the DWM1001-DEV system is naturally inaccurate and overestimates by 60cm, this is the bias value.

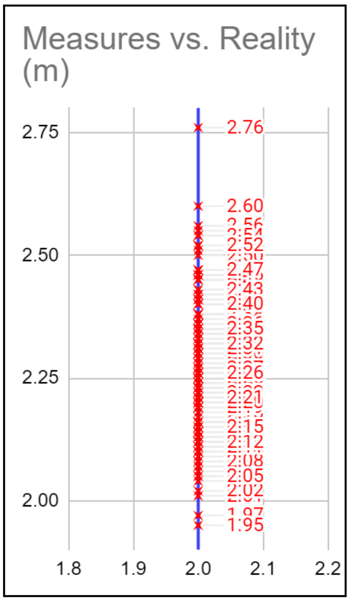
The mean absolute error (MAE) tells us that, on average, each measurement individually is off by roughly 60.4cm.

And finally the standard deviation gives us an idea of the precision of the system. This result means that measurements generally deviate by 14.8cm from one another.

Test results at 2-meter distance:

Mean (m)	**2.27**
Standard Deviation (or precision) (m)	**0.1338111244**
Bias (or accuracy) (m)	**0.26**
MAE (m)	**0.2645294118**





Now if we take a look at the experiment at 2 meters, made over 200 ranging samples, we can see the mean measured value is equal to 2.27m, which again means the DWM1001-DEV system is naturally inaccurate and overestimates by about 26cm. This bias value is slightly better at 2m than what we had at 1m and is closer to the objective we want to reach, which we will go over at the end of this chapter.
The MAE tells us that, on average, each measurement individually is off by roughly 26.5cm, which again is better than at a closer range of 1m.
And finally, the standard deviation only slightly improves, as the result means that measurements generally deviate by approximately 13.4cm from one another.

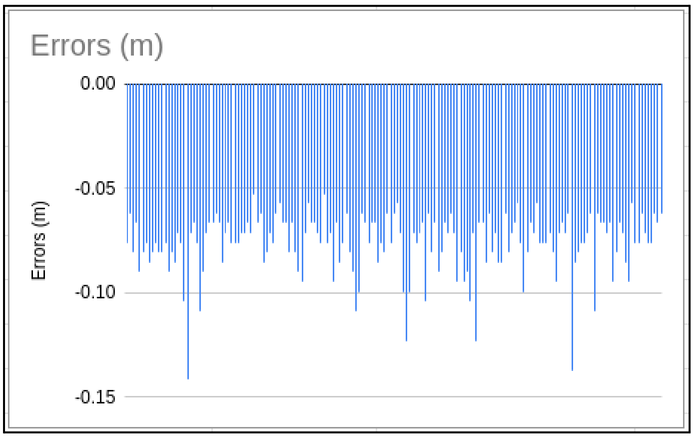
To conclude on this chapter, we can say that testing with the Qorvo DWM1001-DEV boards allowed us to have a great practice with UWB ranging systems, which will be helpful to start testing the NXP boards, as we will see later in this report. We are now able to extract precision and accuracy values from ranging measurements. Compared to our target regarding performance of the system, ideally, we want to be able to position the user with a maximum error of 30cm compared to his real position around or inside the car, at close range (inside a 2m perimeter). These results do not entirely fit in this requirement, especially at closer range, which made us start to think about solutions to improve precision and accuracy, in case NXP's system would perform in a similar way. We will see, later in this report, if we had to face the same issues.

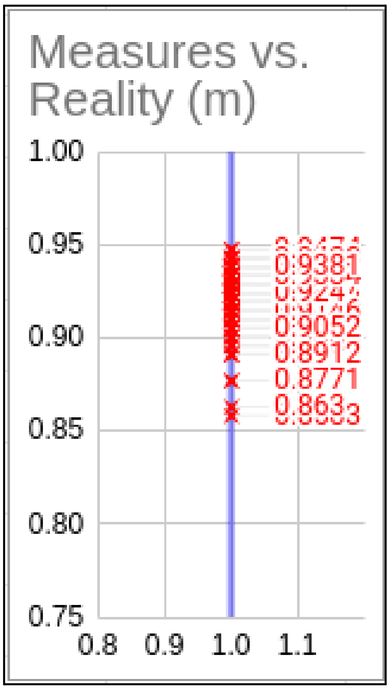
VII. Testing the NXP board and how it compares with our measurements so far

A few weeks after we were able to make our first measurements on the DWM1001 boards, we received the NXP boards and the software attached to it, so we could get our hands on it for the first time and, before anything, make the same experiment as before on them to determine precision and accuracy. So we installed two boards facing each other statically, in the same setup as with the DWM1001, in order to reproduce the same environment and conditions for the measurements. And over 200 ranging samples again, you will find in the following segment what kind of result we obtained.

<u>Test results at 1-meter distance:</u>

Mean (m)	**0.9237909091**
Standard Deviation (or precision) (m)	**0.01447915772**
Bias (or accuracy) (m)	**-0.0762090909**
MAE (m)	**0.07620909091**



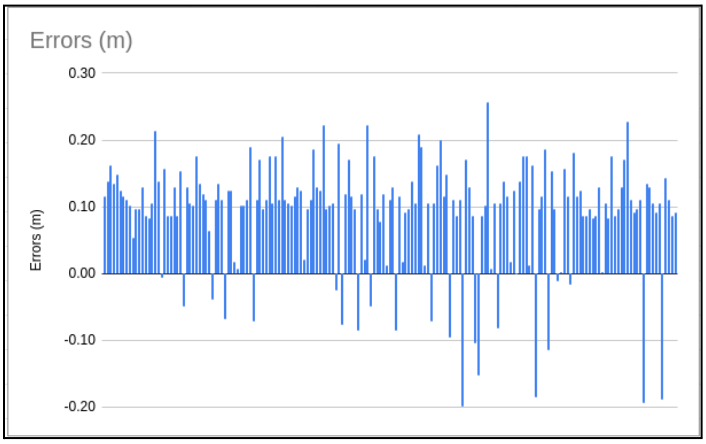


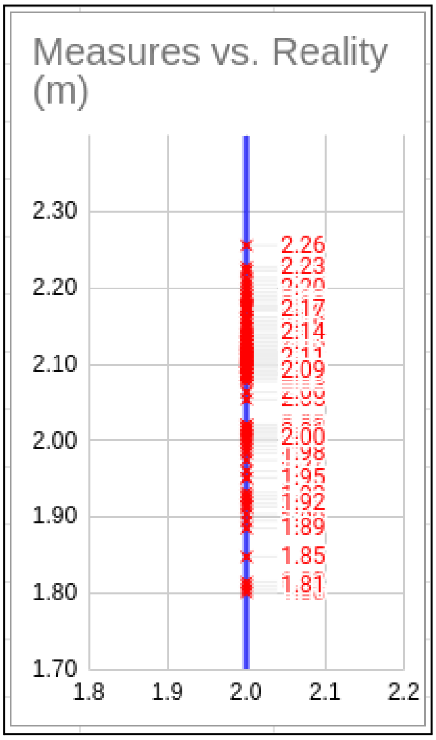
As we can see above, the results are considerably better with the NXP system. At 1 meter, with a mean measured value of ~0.92m, we have an estimated accuracy of ~7.6cm as well as a precision of ~1.5cm. This tells us that even with both errors considered, we would still fit into our 20cm objective by a large gap.

If we compare the precision graph on the right with the one from the DWM measurements, we can appreciate how more stacked the values are, inside only a 10cm interval. Let us now see how that translates at a 2-meter distance.

Test results at 2-meter distance:

Mean (m)	**2.09**
Standard Deviation (or precision) (m)	**0.0852950462!**
Bias (or accuracy) (m)	**0.09**
MAE (m)	**0.1138735**





Here again, with a mean measured value of 2.09m, precision of ~8.5cm and accuracy of 9cm, we would fit the 20cm margin of error. These results were much better than anticipated after the experiment with the DWM1001, which reassured our team a lot regarding overall performance of the system and how it would behave in real outside conditions, which we tested as you will discover later in this report. Furthermore, this meant that maybe we didn't need to put too much effort into correction solutions, especially into testing other ranging protocols, such as TDoA (Time Difference of Arrival), like we originally thought. As you will see, a refining treatment still needs to be applied to the measured value in order to perfect the results.

To conclude on this part, we can say that testing the intrinsic accuracy of the system was essential to help us understand the way it behaves, as well as to obtain our reference on the induced error on each measurement, so we could progress with the project having this in mind. This was the first step to our objective of characterizing the UWB Two-Way Ranging system, in real conditions, to help our partner ACTIA accumulating data on the matter and be ready to think of how to deploy it on vehicles, by acquiring expertise on its functionalities.

VIII. Usage scenarios

Car Scenarios:

The objective was to configure the antennas in the vehicle to replicate the real system, ensuring accurate detection of the user's position and determining whether they are inside or outside the car. We started by measuring the car's dimensions, including its height, length, and width. Markers were then placed at distances of 1 meter and 2 meters around the vehicle (see Figure 1). Finally, we followed a predefined path around the car to analyze and compare measurement variations across different scenarios.

- **First Scenario**

The first test involves installing 5 receivers on the roof of the vehicle, as shown on the left in Figure 2. The 4 antennas are positioned at the corners of a square with sides measuring 40 cm, while the 5th antenna is placed at the center of the square.

- **Second Scenario**

The second test reproduces the first setup, but this time the middle antenna is placed inside the car. This configuration allows us to explore an additional spatial dimension by positioning one antenna at a height different from the others.

- **Third Scenario**

The final scenario involves placing all 5 receivers inside the vehicle: 2 near the windshield, 2 near the trunk, and 1 in the center, as shown on the right in Figure 2. This scenario is particularly interesting because the antennas could serve an additional role as a radar to detect objects near the vehicle, offering a potential solution to optimize energy consumption. However, this configuration is expected to be the least accurate due to the presence of obstacles around the antennas.

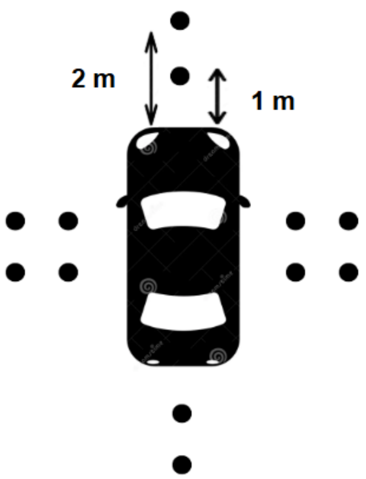


Figure 1 - Markers placement

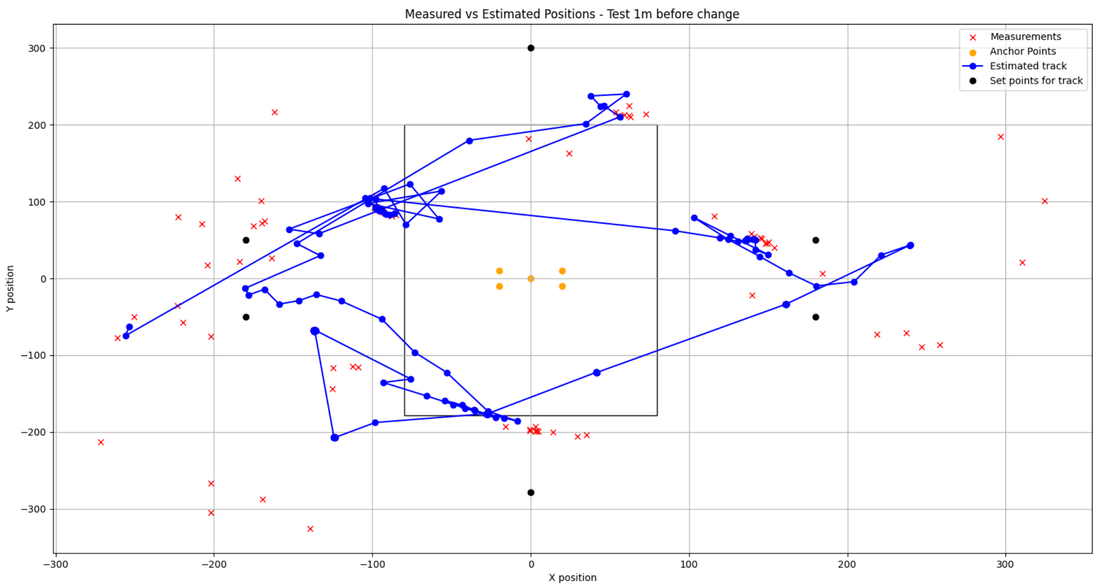
Figure 2 - Antennas configurations

IX. Final results and impacts

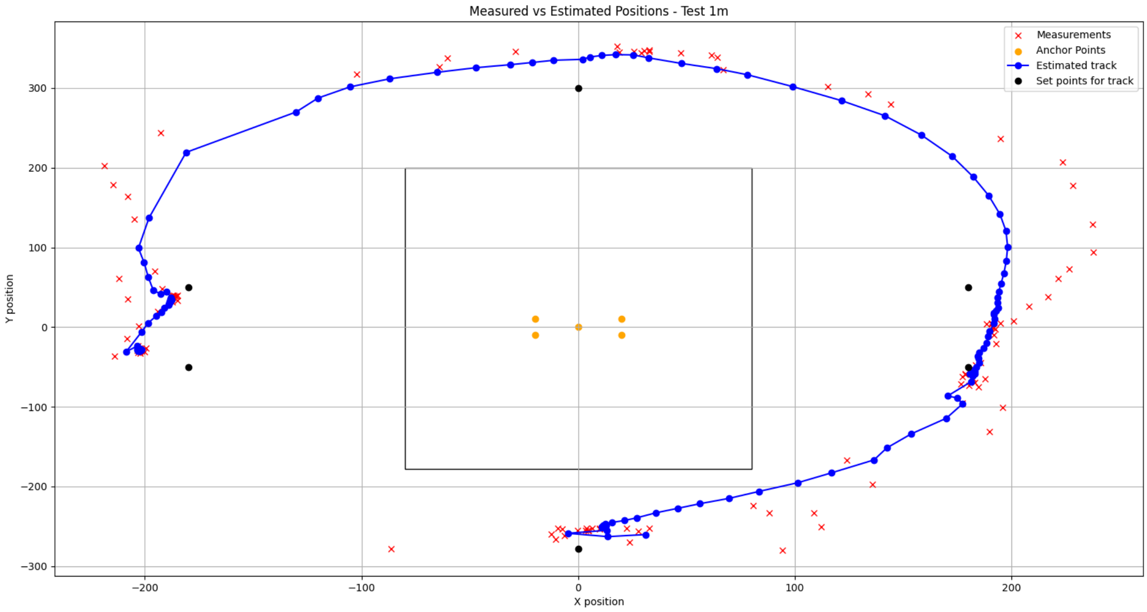
Thanks to the program delivered to us by the Linköping team, we were able to test three different anchor configurations, each with the four different scenarios mentioned earlier. The ranging program on the anchors' side allowed us to directly log the measured distances to each anchor every second. In order to determine each anchor's position in the log file, we had to hold the initiator antenna as close to each anchor in a set order. After that, we were able to use the localization script also given to us.

The results given by the script were unsatisfactory at first, leading us to doubt the accuracy of the system, but upon improvement of the coordinates calculation we were able to obtain satisfactory results, which we will detail further below. In order to improve the aforementioned script, we used the error minimization method of scipy, which calculated the closest coordinates to a point of intersection of five circles, each with an anchor as its center and the measured distance to the initiator as its radius.

Below is a comparison of the resulting graph for the base localization script and for the improved one using minimization :



Plot of the estimated points and track for the 1m radius scenario of the second configuration before improvement of the estimation algorithm



Plot of the estimated points and track for the 1m radius scenario of the second configuration after improvement of the algorithm

We can see that using the minimization method allows for more accurate coordinate estimation, which also allows us to have a much clearer and more accurate estimated track.

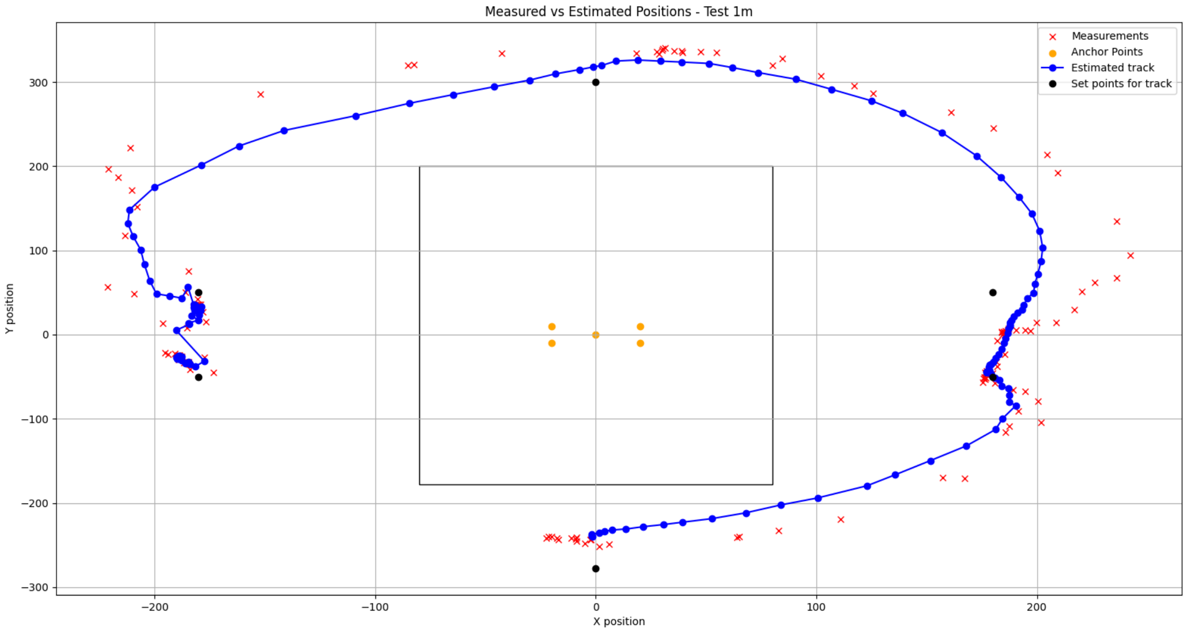
During our tests, some distance logs were incorrect as they didn't respect the set format. There were two such cases, either the log was empty, in which case it was ignored, or the much rarer case where all but one of the anchors detected the initiator. In this case, the log would only contain four distance values. Unfortunately, while it would still be possible to determine the initiator's coordinates with only four(or three) distance measurements, due to the format of the data in the log file, we were unable to determine which anchor lost contact, thus making it impossible to find the coordinates. Because of that, we had to completely ignore these points of data, although they were thankfully extremely rare as mentioned before, only appearing 5 times in all our experiments, and all during the same experiment. This problem could be fixed by modifying the ranging script to display the anchor's id next to each distance measurement. We never had fewer than four distance measurements (except when the initiator lost all connection to the anchors). This is possibly because our tests didn't push the system to its limits, staying in a four meter radius around the anchors and not trying to block or interfere with one or more anchors specifically.

We will now present and compare the result of each configuration.

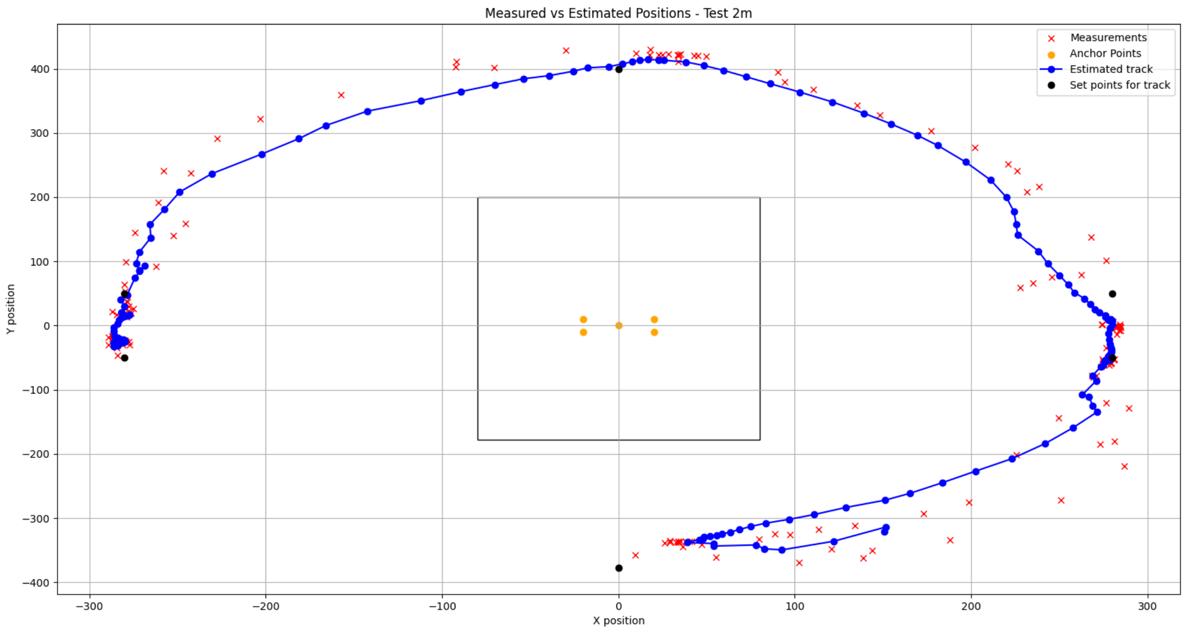
Configuration 1 :

The first configuration is the one which had every anchor on the car's roof in a rectangular pattern, the rectangle being 20 cm wide and 40 cm long. The center anchor was placed directly at the center of the rectangle. The results were as follow :

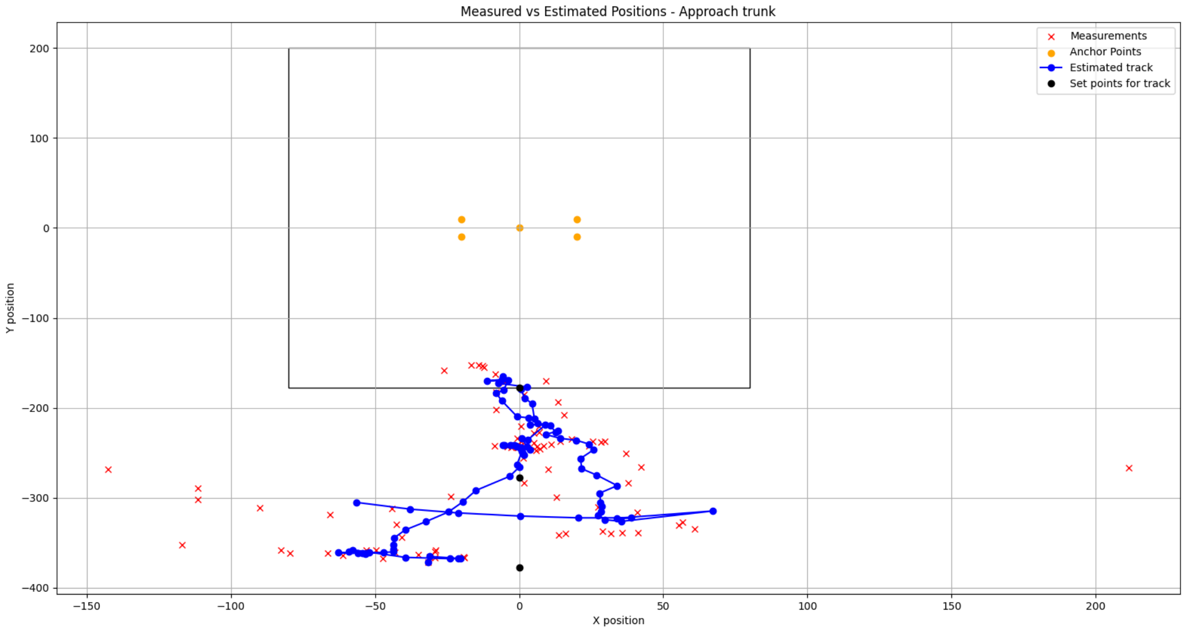
1. Walking in a 1-meter ellipse around the car



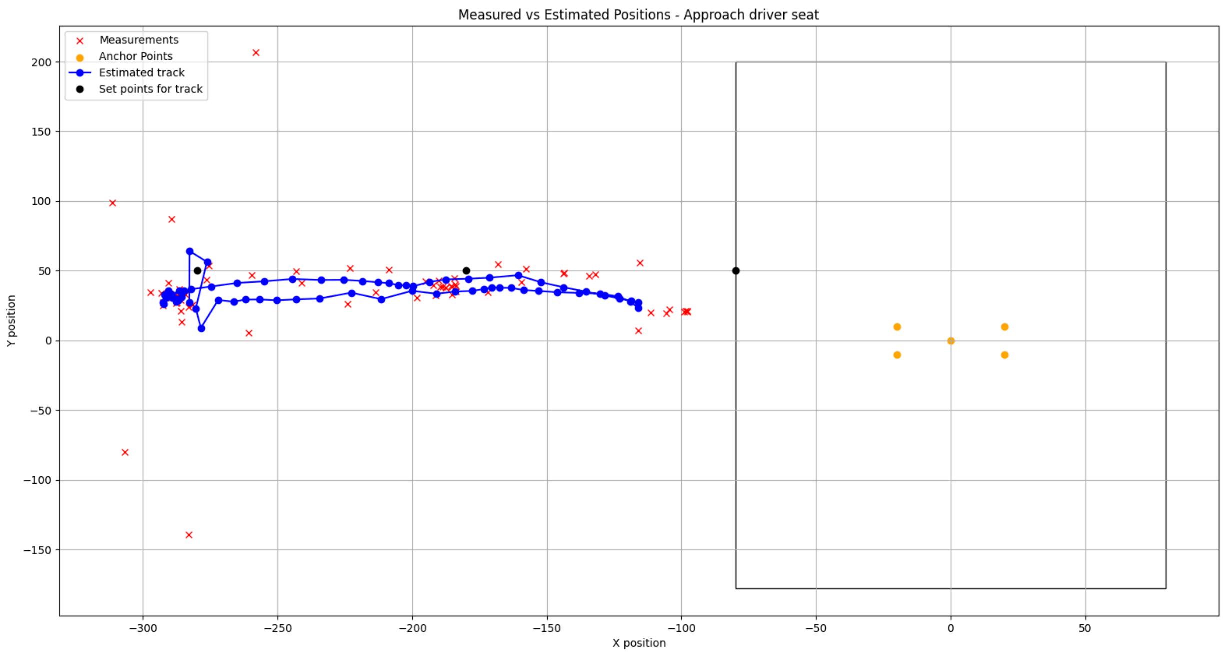
2. Walking in a 2-meter ellipse around the car



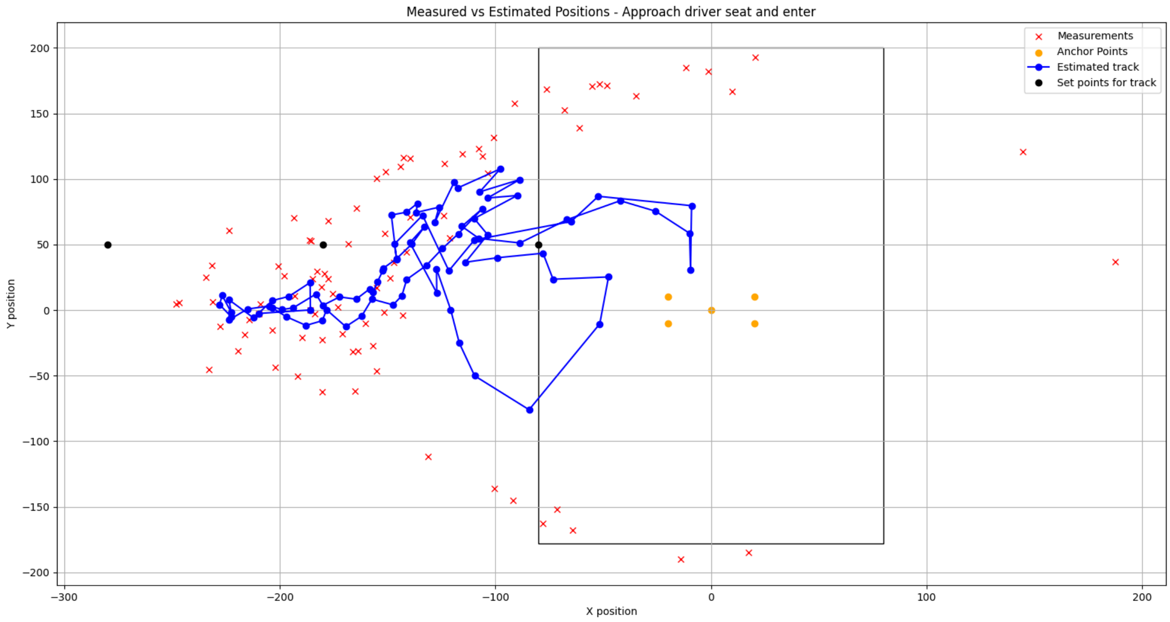
3. Walking from 2m away from the trunk to the trunk and back



4. Walking from 2m away from the driver's door to the door and back



5. Walking from 2m away from the driver's door the entering through it



Some of these first results are already quite satisfying, namely the results for the 1-and-2m ellipses. We can observe that the measured points are mostly in a 10cm radius of their supposed location, and greater errors don't generally affect consecutive points in those scenarios. Although the exact actual track followed is not plotted here, we can see that the estimated track remains a roughly-1-meter ellipse around the edge of the car (plotted as the black rectangle here). Of the other three scenarios, only the approach of the driver's door without entering is as precise.

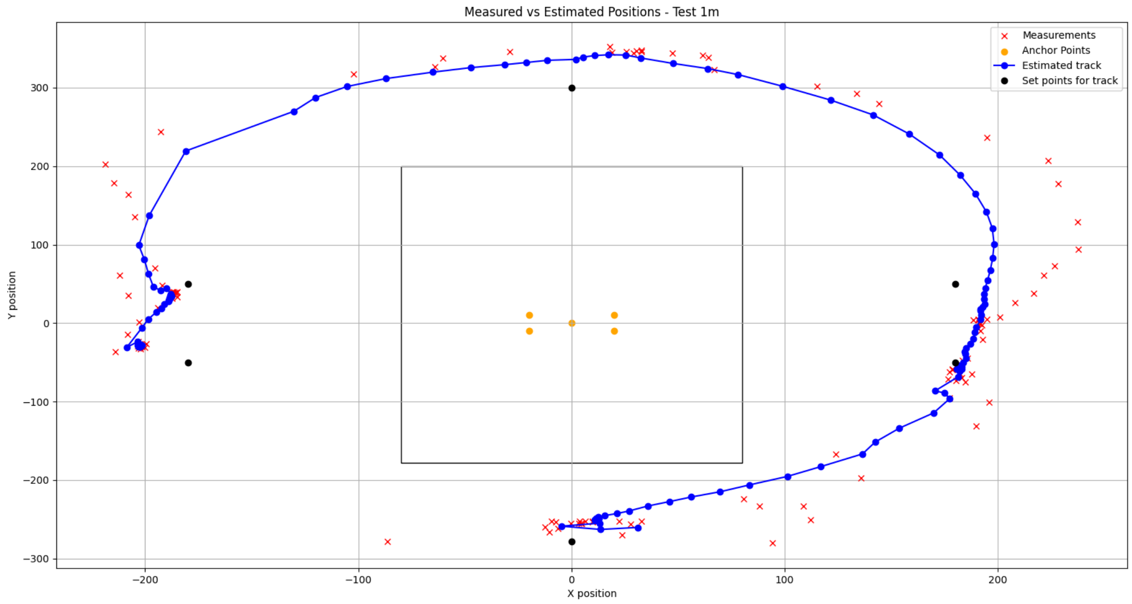
The last two are clearly less satisfactory. The approach of the trunk yielded a decent estimated track (bar a few odd points), but the measurements vary too much, although they do appear to get more consistent and closer to the expected data as we get close to the trunk.

The last one, regarding the approach of the driver's door and entering the car is clearly not what we expect, and considering the accuracy of the other driver's door approach, we can assume that these errors are directly caused by our entering the car. This could be because the metallic armature of the car causes interference with the anchors which were outside.

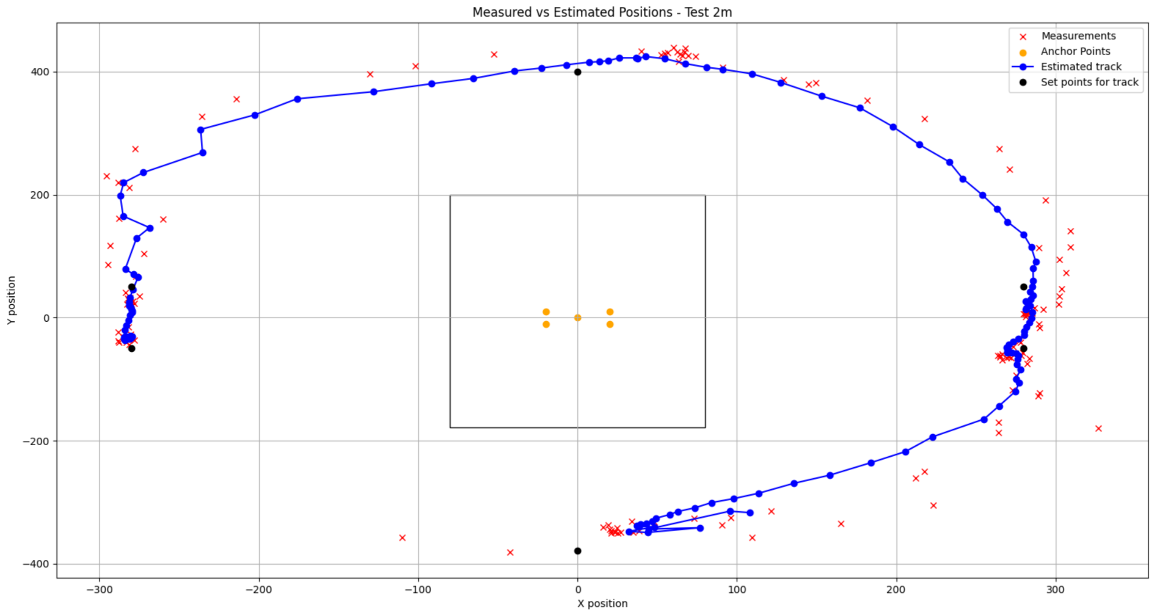
Configuration 2 :

The second configuration is the one which had the four "edge" anchors on the car's roof in a rectangular pattern and the center anchor inside the car. The rectangle's dimensions remained the same and the center anchor was still at its center. The results were as follow :

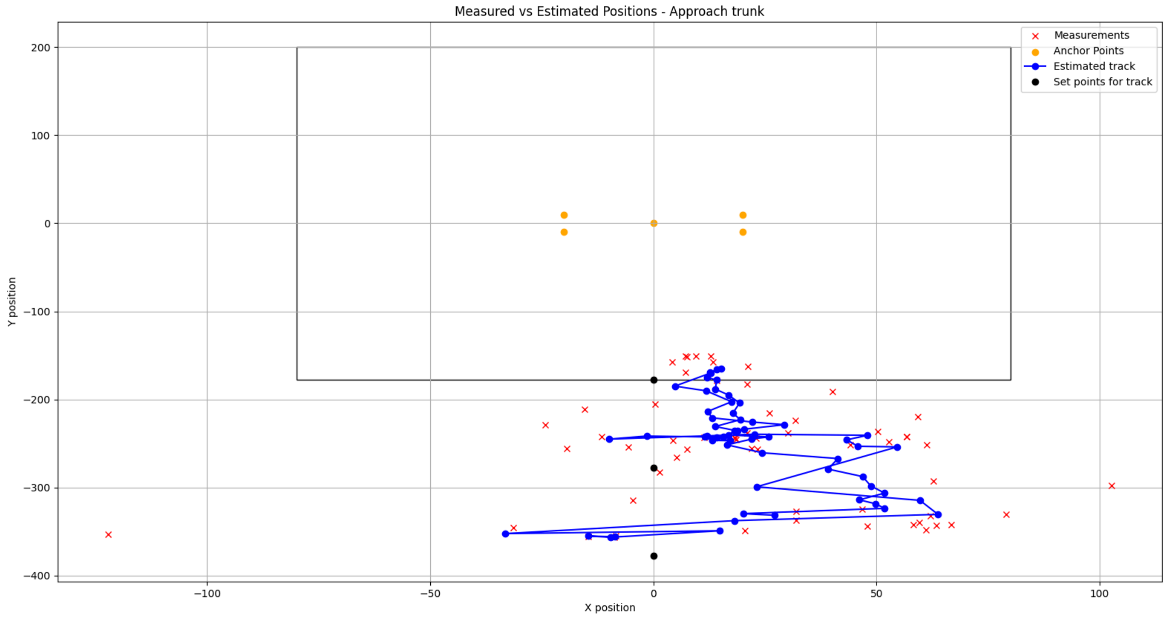
1. Walking in a 1-meter ellipse around the car



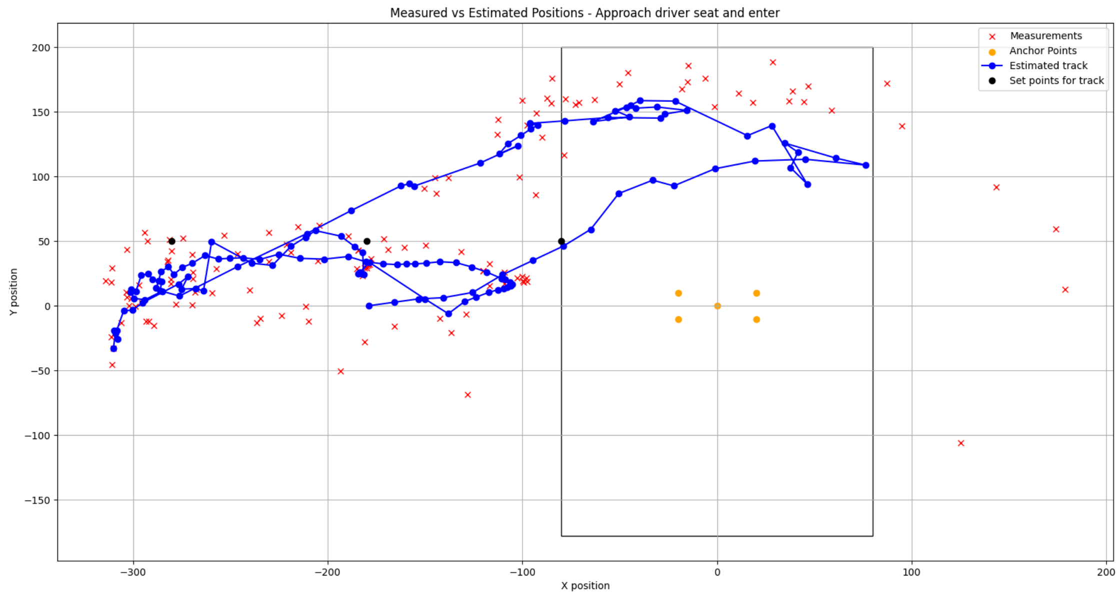
2. Walking in a 2-meter ellipse around the car



3. Walking from 2m away from the trunk to the trunk and back



4. Walking from 2m away from the driver's door and then entering through it



Firstly, in this second configuration, the first two scenarios yielded expected results, similar to those of the same scenarios in the first configuration.

Then the "approaching the trunk" scenario was slightly more satisfactory than in the first configuration, with slightly less scattered measurements, but still presents quite an important variation in both measurements and track.

Lastly, the “approaching the driver’s door then entering the car” scenario is also much more satisfactory, at least as far as the measurements of the user outside the car go. Once the user enters the car, the measurements lose a lot of accuracy. It is however important to note that they are far more grouped than previously, indicating a more stable error which could possibly be determined, predicted and corrected to an extent.

It is also important to note that, while some measurements are inside the area that represents the car, none of them are inside the area that would be the passenger compartment, we would thus not be able to determine if a user is inside the car or not.

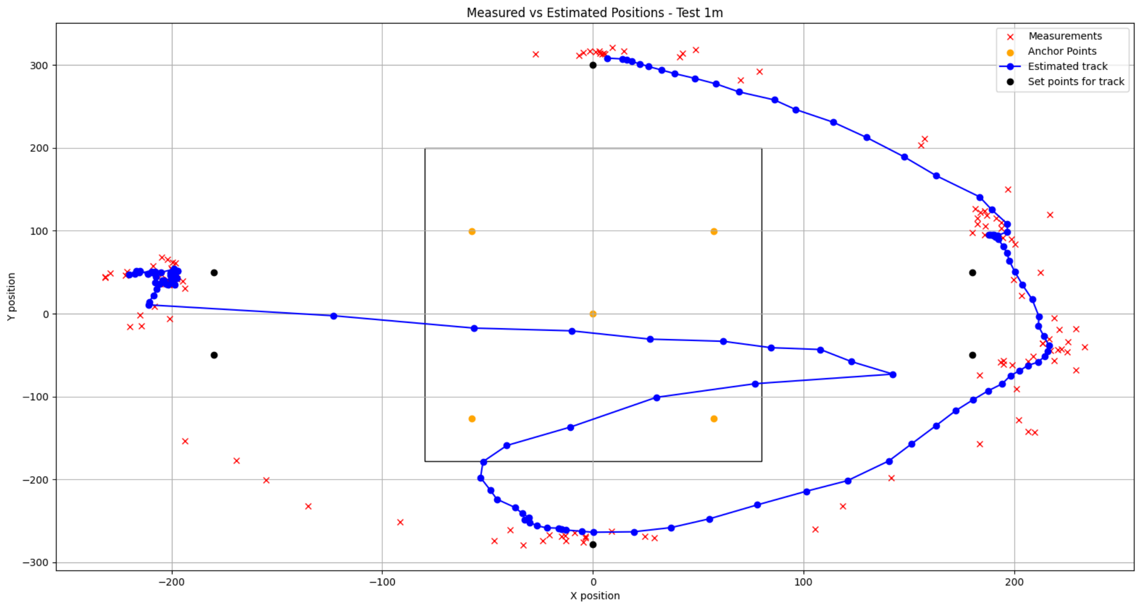
We cut the “approaching the driver’s door without entering” as we didn’t realize its results would be that different during our tests.

Taking all of this into account, this second configuration appears to generally be better than the first one.

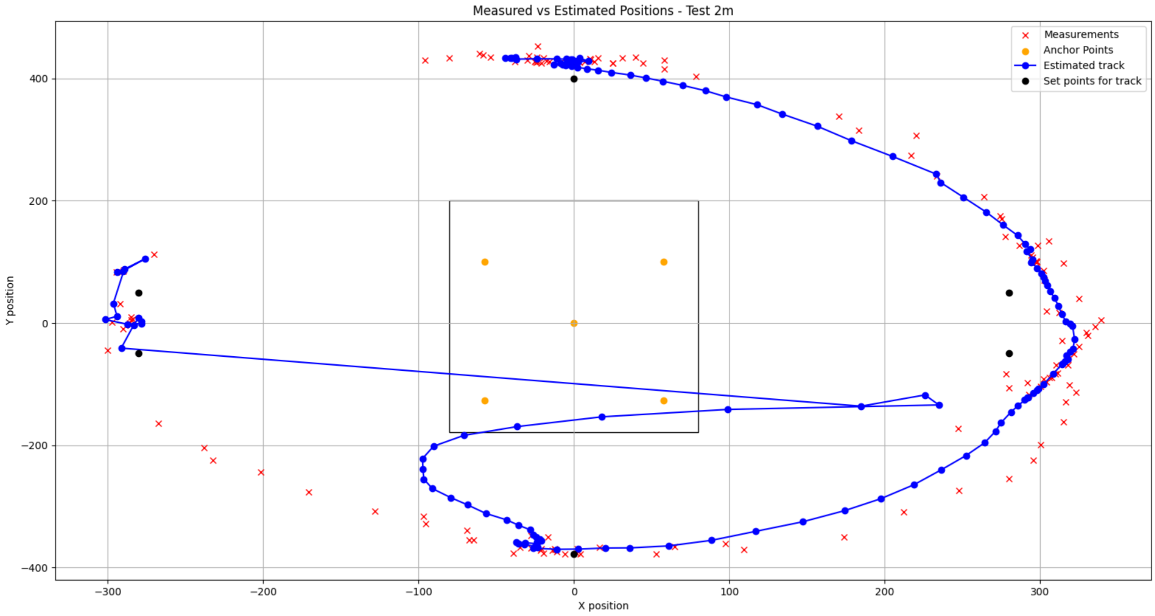
Configuration 3 :

The third and last configuration is the one which had every anchor inside the car in a rectangular pattern. The rectangle was 115 cm wide and 225 cm long, having the edge anchor as close to the edges of the passenger compartment as possible. The “center” anchor was not positioned at the rectangle’s center. The results were as follow :

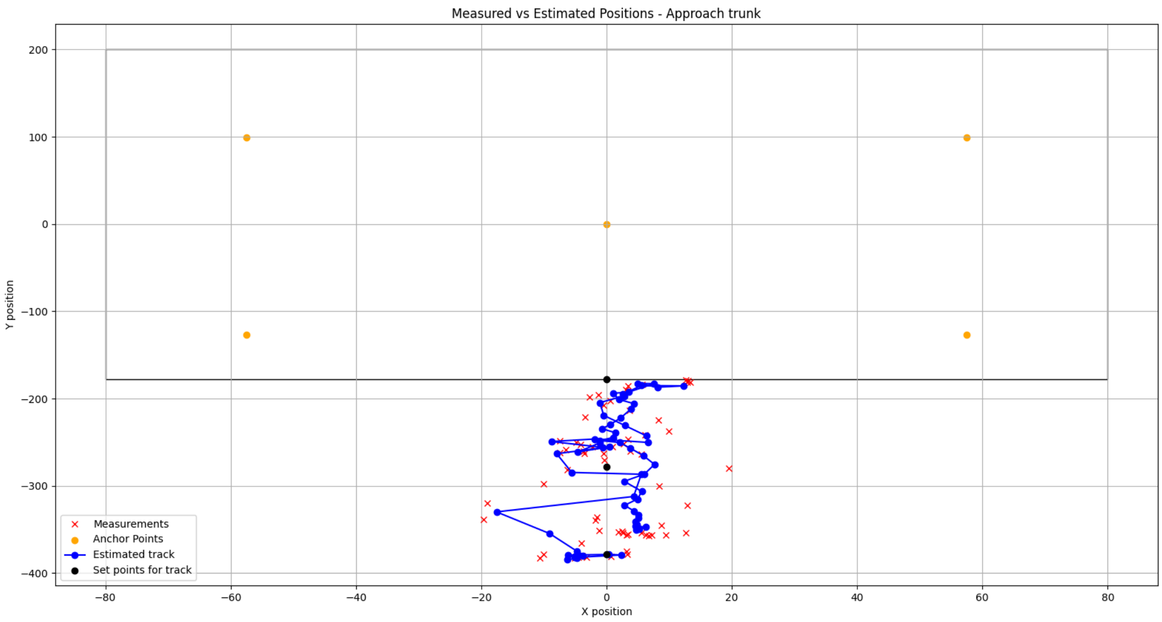
1. Walking in a 1-meter ellipse around the car



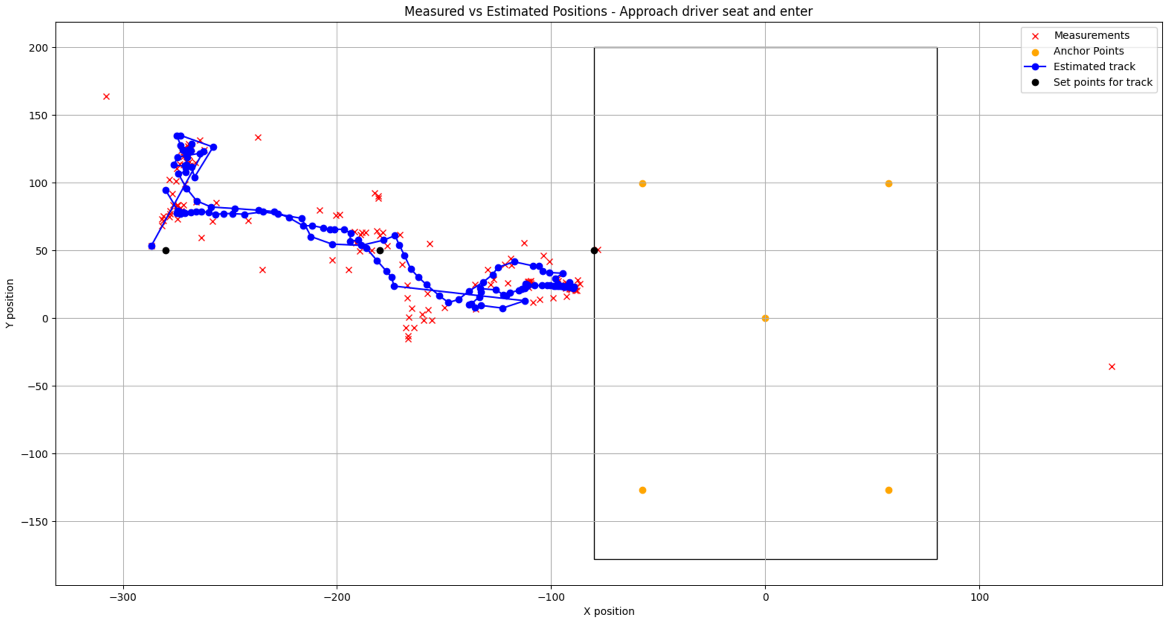
2. Walking in a 2-meter ellipse around the car



3. Walking from 2m away from the trunk to the trunk and back

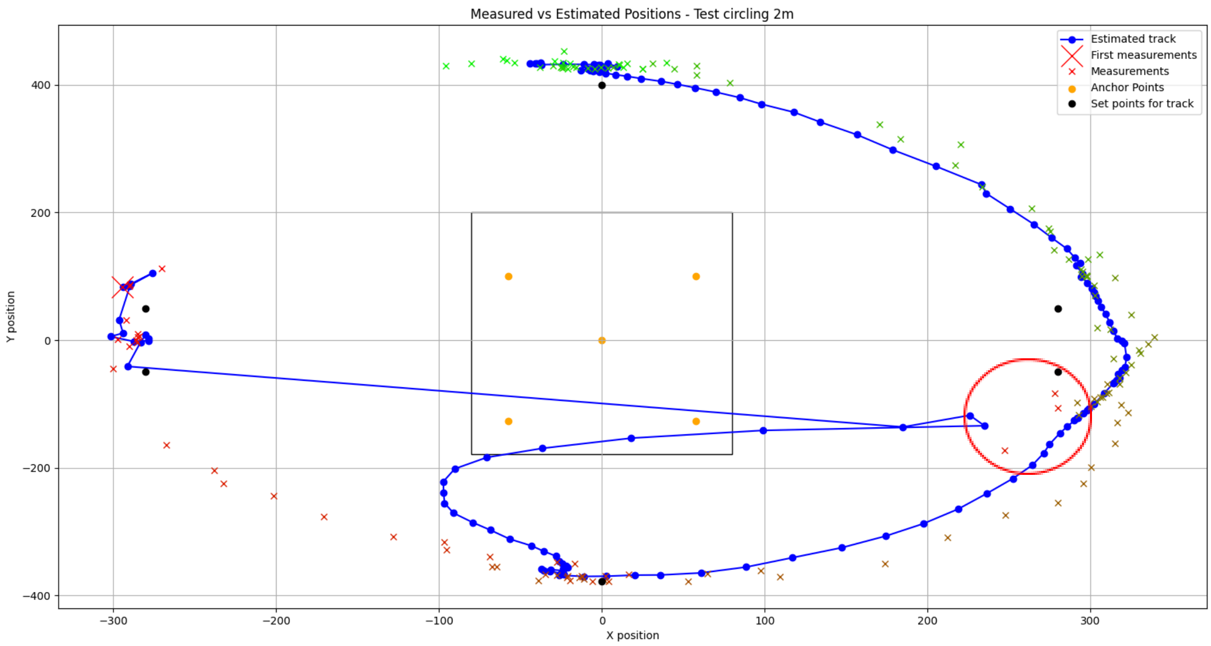


4. Walking from 2m away from the driver’s door and then entering through it



The third configuration already presents a problem in the “walking around the car” scenarios, as we can clearly see the track not following its expected shape, if just for a moment.

We do not however see any weirdly positioned point of measurement, which would indicate that an erroneous point (or group of points) is located with the expected point, except on the opposite side of the car. In order to prove this hypothesis, we decided to change the program slightly to change the color of the plotted points of measure depending on how late they were. The points in the following plot go from red to green depending on the time of the measure.

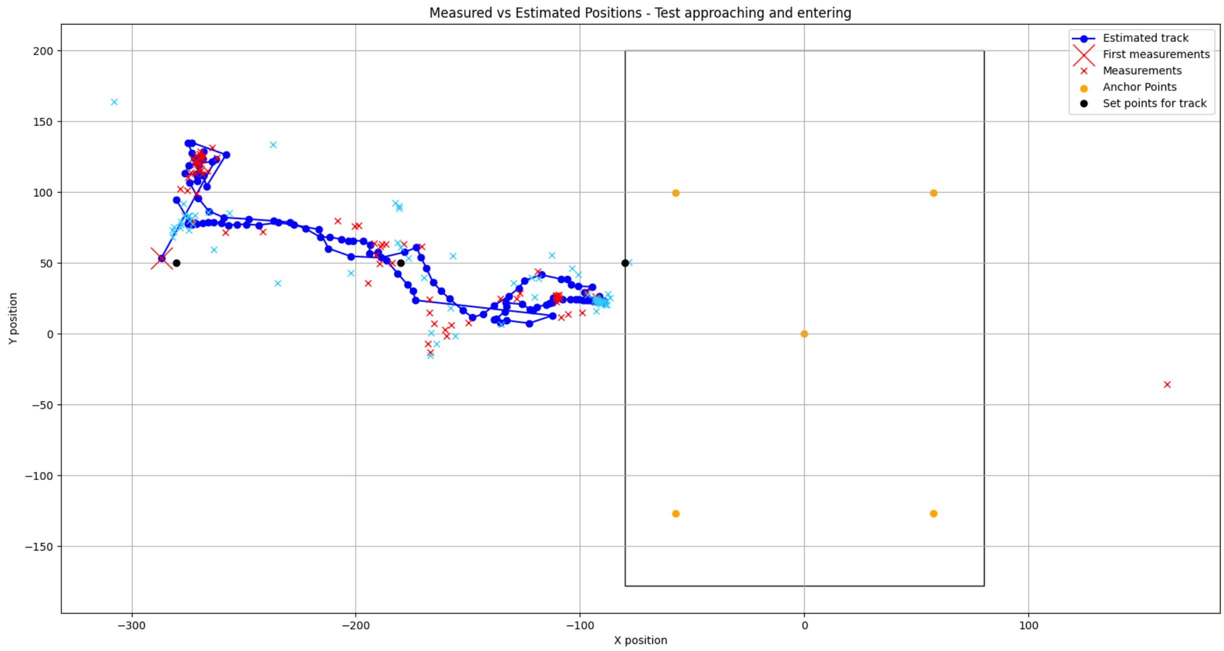


Here, we can clearly see that the hypothesized erroneous points mentioned earlier do exist (circled in red here). Despite there only being three of them, they make the track deviate severely. Other points are around where they should be.

This erroneous set of points is not particularly a problem as we can see that both measurement and track go back to normal shortly after, but it is interesting nonetheless that this happened twice and around the same area. This could be due to an error in our setting the configuration up, rather than in the configuration itself, for example, if an object obstructed an anchor and caused its measurement to be extremely inaccurate, leading to this result.

The “approaching the trunk” scenario, however, is very clearly much closer to our expectations than those of the other two configurations. Here, the largest error obtained is under 20cm, not accounting for our own inaccuracy during the test itself. This leads to a track that is not quite as straight as we would want, but still follows the expected track closely enough.

Finally, the “approaching the driver’s seat and entering the car” also yielded noteworthy results. While not as accurate as the one done without entering the car in the first configuration, it is still accurate at around a meter at most, ignoring two odd solitary points, thus making it much more accurate than in the other two configurations. The main problem with this result is that we only have a single point inside the passenger compartment, and the car in general, where there should be around a dozen. Said point is also directly at the edge of the car, on the driver’s door, when it should be farther inside. Considering this configuration aimed particularly at improving in-car accuracy, it is definitely a disappointing result, especially since we can’t explain it for sure. Perhaps the anchors being positioned on the edges of the passenger compartment and pointed towards the exterior made locating an initiator inside the car particularly difficult. Similar to the test of circling around the car at 2m, we tried improving this result by displaying an approximation of the points that result from the initiator being in the car. Due to no point being detected inside the car, approximating the moment the user entered is not precise and we simply estimated he entered the car at the half-point of the test. This allowed us to get the following plot :



The measurements before entering the car are displayed in red, the others in teal. We can see that points that should be detected inside the car are detected all along the track going towards the car, some even further than the actual start of the track on the left.

Despite this lackluster result for an initiator inside the car, and the odd errors in the “walking around’ scenarios, this configuration has some of the most accurate results, but the second configuration does feel more consistent.

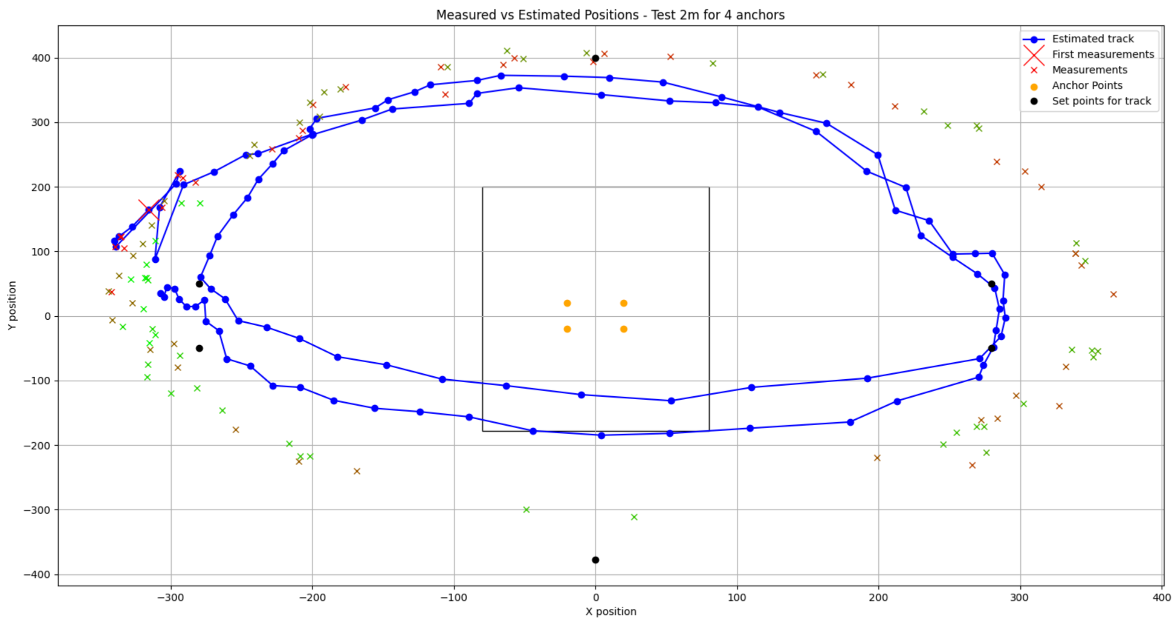
Second set of tests :

After our oral presentation of the project and our result, we, along with Pierre Gruyer, our tutor from ACTIA, decided to have another set of tests to gather more data. We tested three different configurations : only four anchors, all set in a 40x40cm square pattern on the car’s roof, five anchors, the four on the roof in the same pattern and the center one put inside the car on the armrest, facing towards the front of the car, and finally the same as previously but with the center anchor facing towards the trunk. In each configuration, we tried two tests : circling the car twice at two meters and going from two meters away from the car to entering through the driver’s door. For each of these tests, we decided not to point the initiator towards the anchor, instead holding it at waist’s high pointed in front of the user. Below are our results and analysis from these tests. In each test, the first measurement is marked by a large X and the measurements go from red to green the later they are in the test.

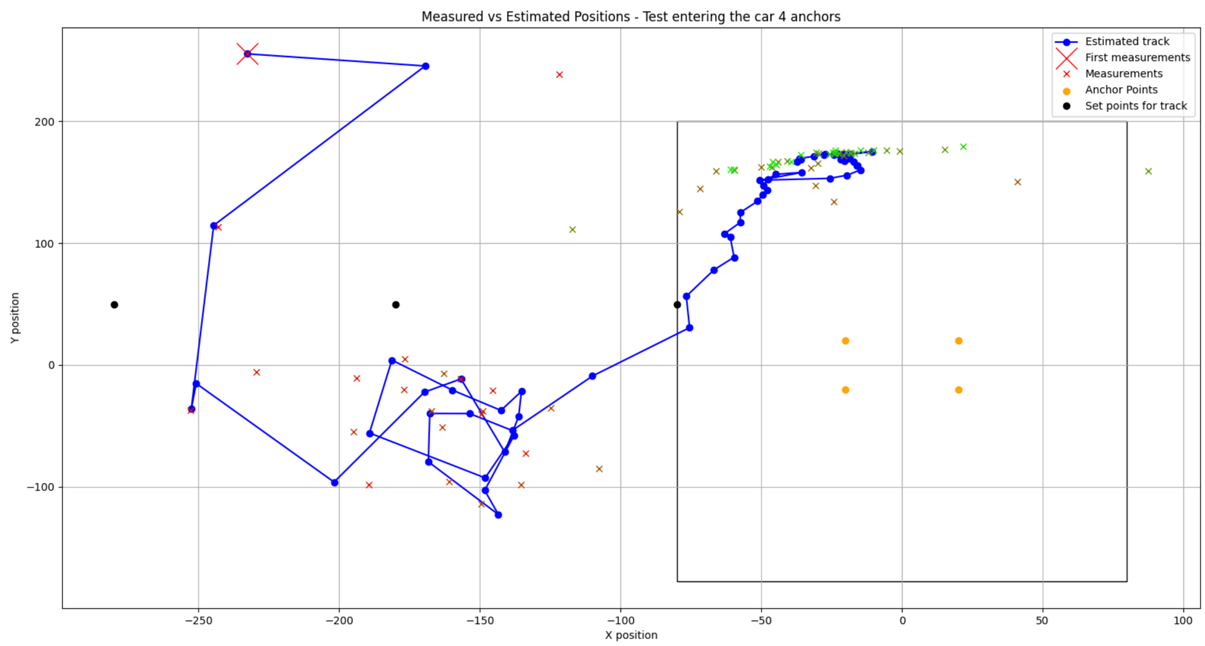
Second set of tests, first configuration

Those are the results for the “4 anchors” configuration

1. Circling at 2m



2. Walking from 2m away from the driver’s door and then entering through it

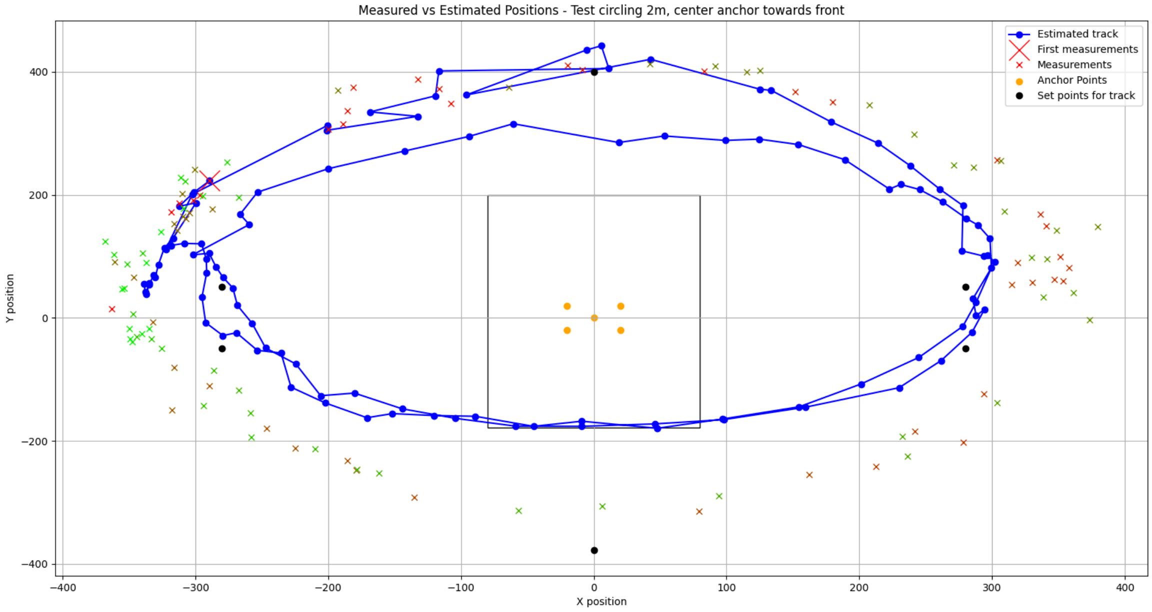


These results are fairly unconvincing. The circling of the car is decent, but we struggle to detect the user when behind the car, leading to the computed path being much closer to the trunk than it should be. We manage to detect the use entering the car fairly well, but weirdly enough the approach that comes before is not too close to the expected results, being lower on the y-axis and more scattered than on previous similar tests.

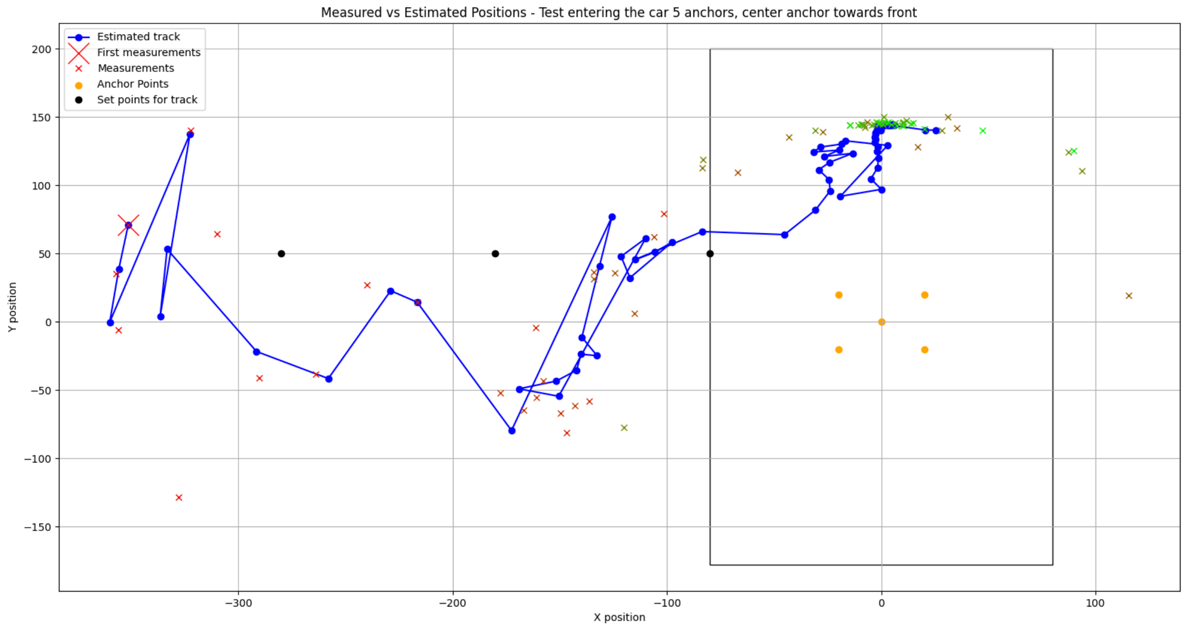
Second set of tests, second configuration

Those are the results for the “5 anchors, center pointing to the front” configuration

1. Circling at 2m



2. Walking from 2m away from the driver’s door and then entering through it

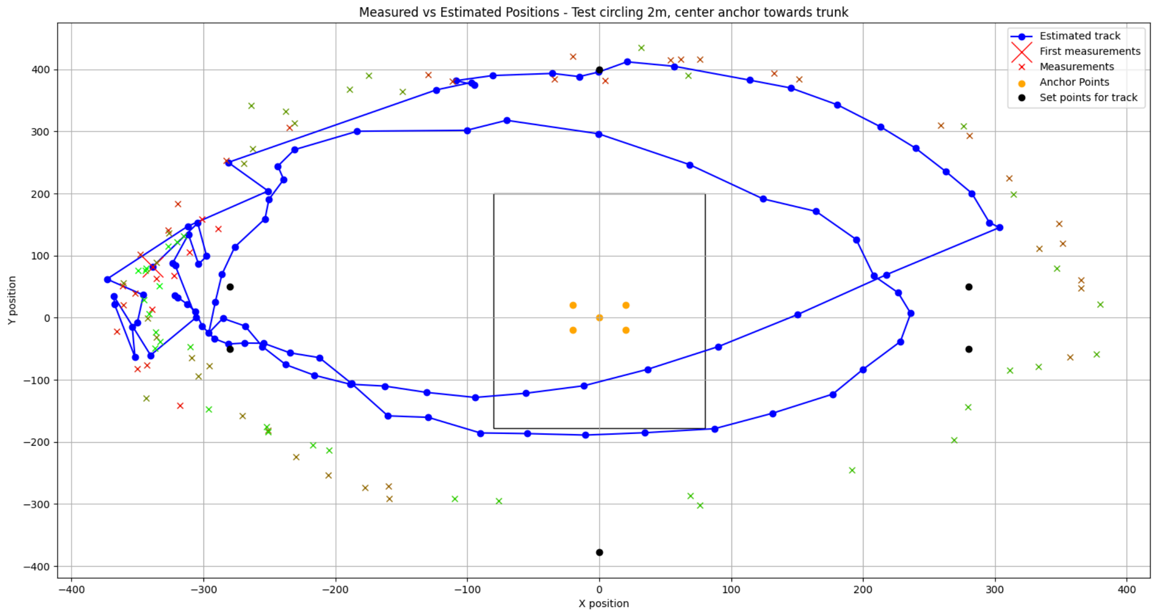


For the circling test, these results are fairly similar to that of the first configuration, maybe only being slightly more precise and less scattered. We suffer the same problem of having very few points behind the car. Approaching the driver’s door is also less scattered, but still not very satisfactory. However, once inside the car, the results are closer to reality and grouped closer.

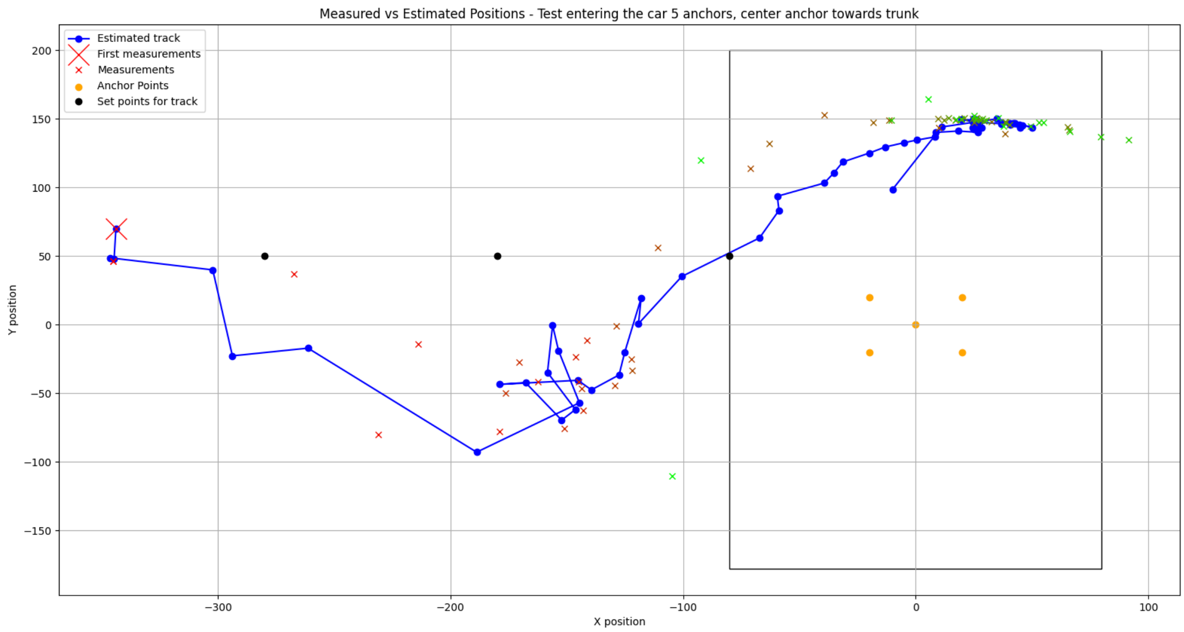
Second set of tests, third configuration

Those are the results for the “5 anchors, center pointing to the trunk” configuration

1. Circling at 2m



2. Walking from 2m away from the driver’s door and then entering through it



Finally, this configuration probably presents the worst results of the three. We have even fewer points around the trunk on this one, skewing the estimated track even more. The measurements we got on the right side of the car on the plot are also further from their expected location than in the other 2 configurations. For “approaching the car”, the results are probably the most satisfactory, but not by enough compared to the loss observed when circling the car.

Those results are overall disappointing. They are not terrible but aren't as good as what we had previously got. The two most likely explanations for that are : the computer we used to get the results from the anchors was positioned directly behind them due to issues with cable lengths. This may explain partially why we struggle to detect the user behind the car. The second explanation is that those tests were done closer to reality than the other ones. As mentioned before, the initiator wasn't pointed towards the anchors, nor was it at the same elevation, leading to errors in distance measurements and overall being harder to detect and correctly estimate. We were also moving at a constant pace. During our first tests, we observed that movement tended to make detection and measurements harder for the anchors, leading to us stopping at set locations to let the anchors gather data. Moving at a set pace probably led to some measurements not being as accurate, but also means that these results are closer to what we should expect in a real life application of the system.

X. Energy

UWB technology stands out as a reliable solution for high-precision ranging and localization. However, integrating it into a vehicle presents specific energy challenges. Here, we will explore solutions to address these challenges by combining energy efficiency, sustainability, and robustness.

The TWR (Two-Way Ranging) UWB system primarily consumes energy for signal transmission, data reception and processing, and algorithmic computations. Estimating active and standby cycles is critical to optimize overall power consumption.

We have potential energy sources in a vehicle :

Main Power Supply	Energy Harvesting	On-board Solar Panels
The vehicle's battery (12 V or 24 V) can be used via a DC-DC converter to adjust the voltage to the UWB system's needs.	**Kinetic Energy**: Using vehicle vibrations with piezoelectric sensors. **Thermal Energy**: Exploiting thermal gradients from the engine or cooling systems through thermoelectric devices. **Electromagnetic Energy**: Capturing ambient RF waves, especially for standby modes.	Flexible solar panels can provide a complementary energy source to charge supercapacitors or secondary batteries.

Efficient energy management is vital for ensuring the reliable operation of a UWB system in a vehicle. A Power Management Unit (PMU) serves as the core component, seamlessly coordinating multiple energy sources. Supercapacitors address instant, high-demand energy pulses, while secondary batteries ensure stable and long-term power availability. To optimize energy consumption, low-power modes can be utilized during inactive periods, signal processing algorithms fine-tuned for efficiency, and transmission power adjusted to match operational requirements.

If we want to integrate the system into a vehicle, it requires addressing environmental challenges such as extreme temperatures, constant vibrations, and electromagnetic interference is crucial for robust system performance.

For this project, we propose a hybrid energy model, integrating the vehicle's main battery via a DC-DC converter, piezoelectric sensors for vibration energy harvesting, supercapacitors for immediate power needs, secondary batteries recharged by solar panels or thermoelectric devices, and a PMU to manage these components efficiently.

This approach ensures a sustainable, resilient, and adaptable energy framework for UWB systems in automotive environments.

XI. Security

Passive Keyless Entry Systems (PKES) offer users maximum convenience by allowing vehicle access and ignition without physically using a key. However, these systems are vulnerable to relay attacks, a sophisticated technique used by attackers to exploit the system's reliance on proximity mechanisms.

In a typical relay attack, two attackers work in coordination. The first attacker positions themselves near the vehicle and uses a device to relay the vehicle's communication signals. Simultaneously, the second attacker places themselves near the legitimate key, often located inside a building, to intercept and retransmit the key's response back to the vehicle. This effectively bypasses the proximity authentication mechanism.

The attack leverages the trust of the PKES system, which assumes that the presence of a key signal near the vehicle implies physical proximity. By bridging the communication over a significant distance, the attackers trick the system into unlocking and starting the vehicle. This process is illustrated in the accompanying figure, which details the sequence of the attack:

1. The vehicle transmits signals to locate a legitimate key.
2. The second attacker captures these signals and relays them to the first attacker.
3. The first attacker retransmits the key’s response to the vehicle, successfully gaining unauthorized access.

This vulnerability underscores the importance of developing secure PKES systems capable of detecting and mitigating such attacks, ensuring enhanced safety and reliability for users.

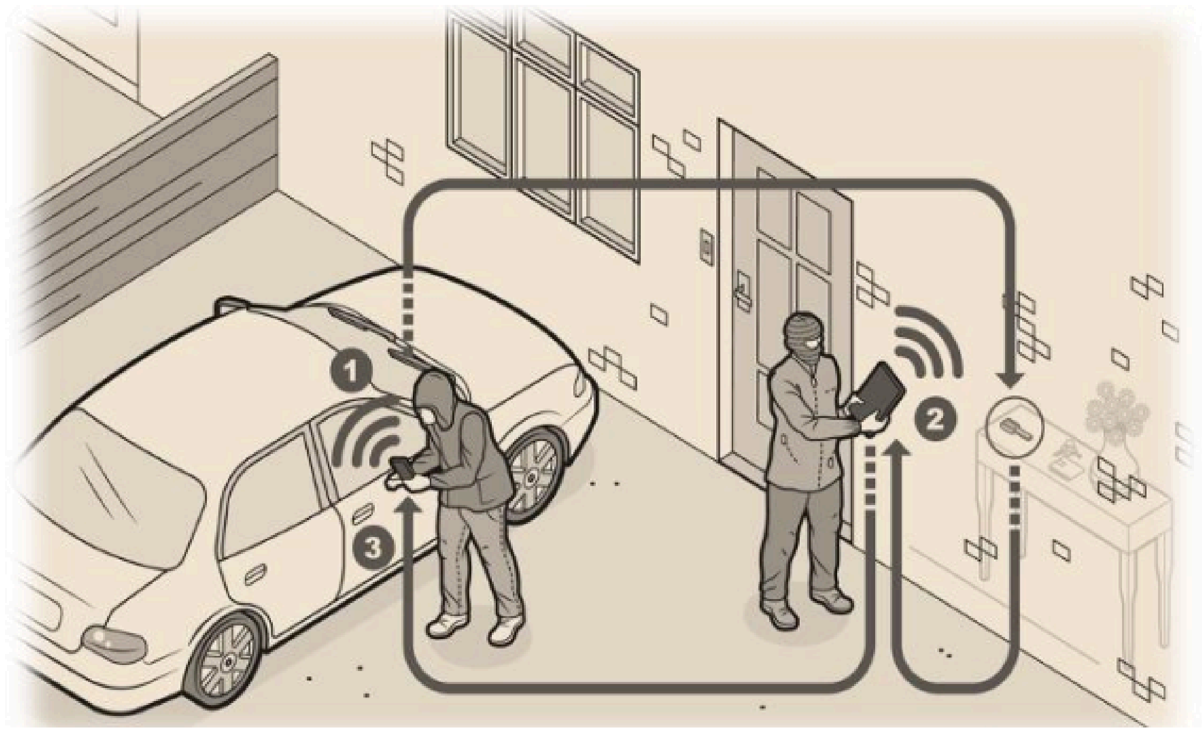


Illustration of a Relay Attack Exploiting Vulnerabilities in Passive Keyless Entry Systems (PKES)

Relay attacks exploit the lack of time sensitivity in traditional proximity-based systems. Attackers use a pair of devices to extend the signal between an electronic key and the car, creating a "tunnel" that tricks the vehicle into believing the key is within range. This bypasses proximity authentication mechanisms, enabling unauthorized access and ignition.

UWB technology is inherently resistant to such attacks due to its high temporal resolution and precise Time of Flight (ToF) measurements. Unlike traditional systems, UWB accurately calculates the time it takes for a signal to travel between the key and the car. This precise timing allows it to identify discrepancies introduced by relaying devices.

In a relay attack, the attackers introduce additional delay when extending the signal. UWB detects these delays through its precise ToF measurements. For example:

- If the key is located 1 meter from the car, the Time of Flight (ToF) is approximately 3.33 nanoseconds.
- If the key is located 5 meters away, the ToF increases to 16.67 nanoseconds.

In normal operation, the system expects the key to be within a specific radius, such as 1 meter. If a relay attack is attempted, the extended distance introduces a significantly higher ToF. The system detects this anomaly and rejects the signal, effectively preventing unauthorized access.

This ability to identify and mitigate relay attacks highlights the enhanced security provided by UWB technology. Its precise timing capabilities ensure that only legitimate keys within the authorized range can interact with the vehicle, making it a robust solution for modern Passive Keyless Entry Systems (PKES).

XII. Conclusion

To close this report and chapter of our engineering experiences, we would like to say that this project gave us an incredible opportunity to make a step in the integration of Ultra Wideband (UWB) technology into automotive systems, with a focus on accuracy, but also openings towards security and energy efficiency. By thoroughly investigating the potential of UWB for vehicle access systems, we believe that we have demonstrated its accuracy, and robustness, hoping that this could help setting a new standard for the modern vehicle industry.

By experimenting with different configurations, we were able to identify optimal setups to achieve considerable accuracy even in challenging scenarios. Even though certain limitations, such as in-car localisation, were observed, the lessons learned provide a strong foundation for further refinement. By addressing the challenges with innovative solutions, such as error correction algorithms and by proposing a hybrid power management for the system, we aimed at ensuring the sustainability and reliability of the proposed system.

In addition, working with industry partners and international teams was an experience of great value to us. It gave a real meaning to the project and gave us the will to achieve practical and impactful results. This partnership not only enriched our technical expertise, but also demonstrated the value of teamwork to face engineering challenges.

As a conclusion, the successful outcomes of this project underline the transformative potential of UWB technology in the automotive domain. The results could pave the way for future innovations, ensuring enhanced safety, user convenience and technological advancement in connected vehicle systems. Our findings provide a good amount of data and an interesting starting point for scaling these solutions for commercial applications, with the vision of shaping the next generation of intelligent automotive systems.