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MIDDLE EAST TECHNICAL UNIVERSITY

Electrical & Electronics Engineering Department

EE493 - Engineering Design I

"Cısss!"

Conceptual Design Report

Company Name: λambda

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1. Executive Summary

Nowadays, many individuals live with their pets in their homes. They treat their pets as children and do not separate them from their families. However, at times, these friends may be as mischievous as they are adorable. They could wander out the front door and leave the house, or they might climb the kitchen countertops to eat something they shouldn't. Pet parents need a tool to keep their dogs from hurting themselves or making a mess by preventing misbehavior. This is when λambda enters the scene.

Lambda is proud to present a revolutionary gadget that aims to prevent pets from possibly harmful behavior, a current gap in the market. The proposed product is designed to be worn on the pet's collar, however, customers may have their pets wear it however they choose, thanks to the compact design of the device. The primary device, referred to as the "master unit," is designed to be as compact and light as possible so that the wearer does not experience any irritation. The product does not solely consist of the master unit, however. The device also includes tags that the user may place wherever in the house that they want to label as "forbidden places." The master unit will inform the pet if it trespasses, or approaches these restricted regions without hurting the pet. The intended alerting mode is acoustic and vibrational. Given that thousands of pet owners face the mentioned issues on a daily basis, it's clear that a device that can prevent risky behavior in animals without harming them has enormous market potential.

The document you are about to read is the conceptual design report of the described product, which contains detailed technical information on how the product is being developed, and what to expect from the final product.

2. Introduction

The project to be presented, named "Cısss!" is a smart device aiming to make life easier for pet parents. The device consists of two parts, the master unit, and several tags. The master unit is a wearable smart device, which detects the presence of tags nearby to alert the wearer (the pet) of its wrongdoing. The tags may be placed in open areas, as well as doorways up to 90 cm wide to "label" it as forbidden. When the pet approaches the forbidden zone, the device alerts the pet with no harm given. The master unit is compact and safe, causing no discomfort or damage to the animal.

Currently, the device is in development, and a prototype for testing purposes has been created. The prototype consists of two CC2640R2 evaluation boards that function as the master unit and tag. The two boards communicate over radio frequency wave radiation, and the master unit uses the received signal strength indication (RSSI) value of the wave to deduce the tag's distance. The master unit then lights the onboard LEDs to infer the distance. The computed distance, the RSSI value, or any other intermediate values may be sent over UART to a connected computer, and viewed as a real-time graph if wished to. The conducted tests show that the computed distance is accurate as was desired for this point for the controlled experiment. However, the accuracy is hurt under some scenarios, which have been identified.

In this report, you will find not only the current progress on the project, as well as future plans on more features to be implemented. The proposed solution on how to tackle the problem and some alternative plans are presented. Furthermore, a more detailed analysis on each of the subsystems, including both the already implemented and planned to be implemented features comes next. Test results of the current prototype of the device, which identify possible problems that were observed, and contingency plans on how those problems may be tackled are also discussed. Further details such as the team's management structure and expected deliverables may also be found in the report.

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3. Solution Procedure

Overall system is divided into three subsystems, and the system level flowchart is presented for a better understanding of the structure. In this section; firstly, the overall system block diagram and the objectives are given. After that, the system-level flowchart and each subsystem are explained in detail with alternative solution methods. At the end of the section, test results are provided.

3.1. Overall System

As indicated in the above sections, the company aims to design a compact, low-cost product with low power consumption. However, there is a trade-off between these objectives. Therefore, the company's objectives for this project are as follows:

- If the pet crosses the predefined boundary of the tag, it will be warned **in at most a second.**
- The product will be able to sense four different distance ranges to **warn the pet in four stages of increasing alarm strength**.
- The dimensions of the master unit need to be as small as possible since the pet will be wearing it. Therefore, the **dimensions must be at most 20cm x 15cm x 7 cm**. The product's shape can vary; it does not have to be a rectangular prism. A simple concept of the devices has shown in Figure 3.1.
- There is no metric for the stability of the project, but **the system needs to be as stable as possible**. For example, if the pet is stationary but the system switches between alerting and non-alerting modes, that means the system is not stable as desired.
- Since the device's wearer is a pet, it **should not weigh over 100-150 grams.**

- Both the master unit and the tags should be able to be powered with a **single-button battery**, which will be able to keep it powered up for **at least two weeks**.

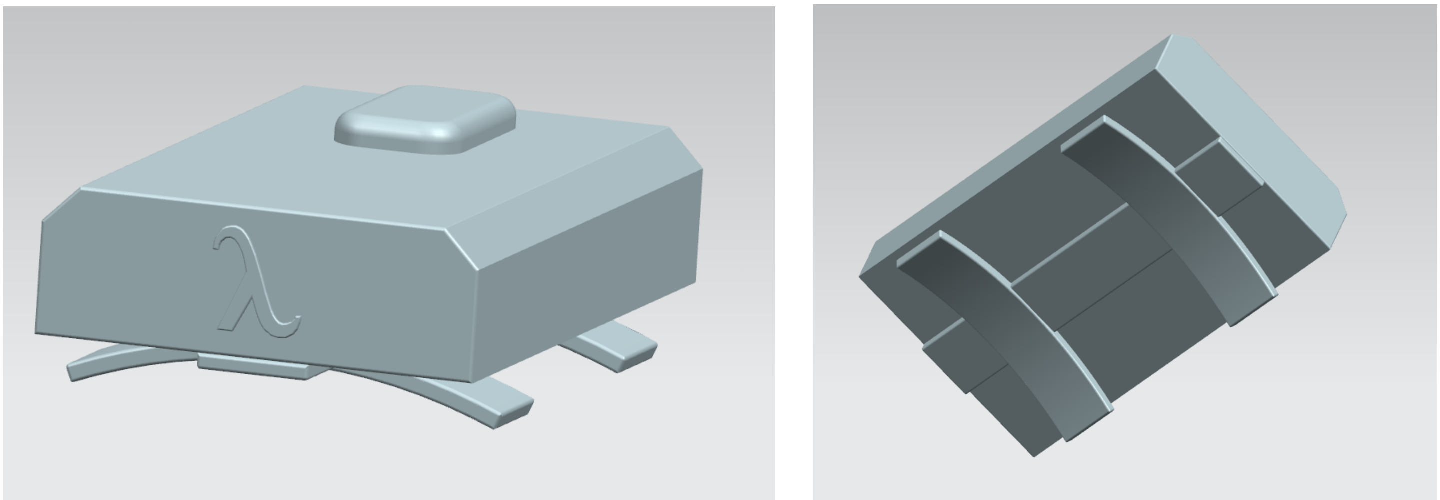

Figure 3.1 *Proposed design of the master unit case*

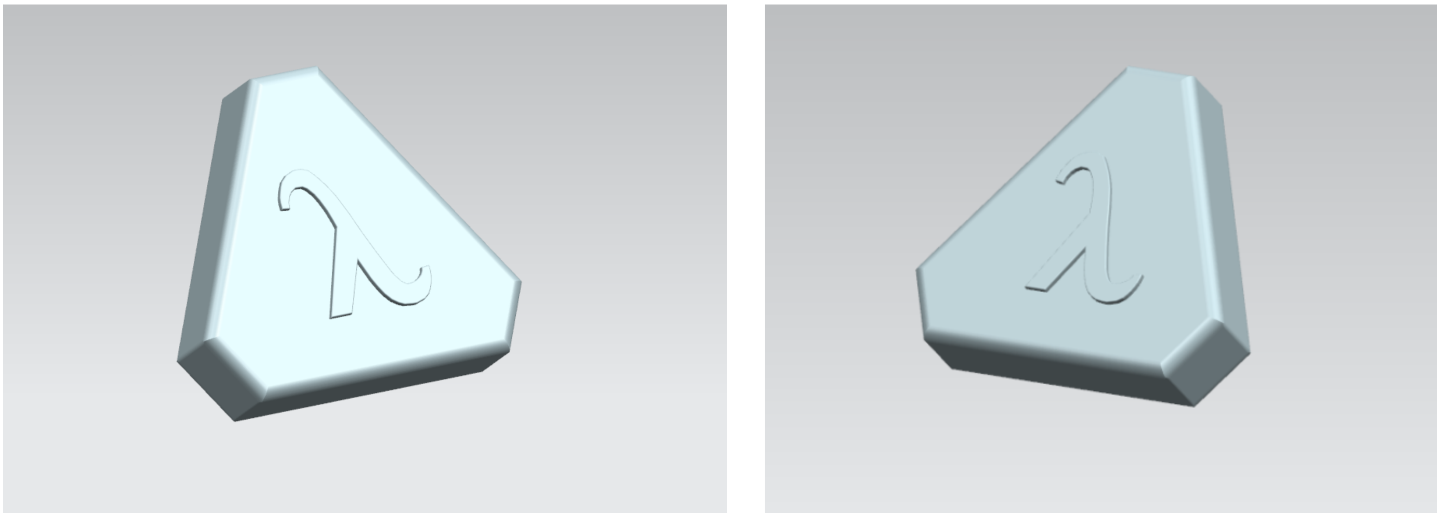

Figure 3.2 *Proposed design of the tag case*

Note that these drawings are purely a concept & during the integration process, these designs may change according to the test results obtained during the optimization phase of the project.

The working principle is quite straightforward. The detection system detects the presence of a tag (or the master) being in proximity, and starts communicating over RF. The communication between the units allows the control subsystem to deduce the estimated distance between the units based on the strength of the signal received. Depending on the computed distance estimation, the control subsystem informs the alerting subsystem to adjust its alerting strength accordingly if need be. Finally, the alerting subsystem warns the pet by causing a sound and vibrating.

Figure 3.3 *Subsystem Block Diagram*

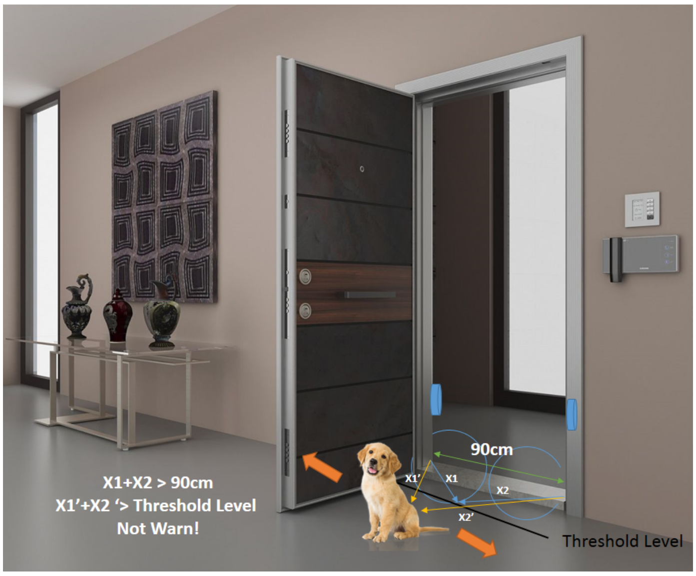

Figure 3.4 *Door tag explanation* **Figure 3.5** *Explanation continued*

The figures above show our current plan of differentiating a doorway forbidden zone from a zone tag. The working principle of the zone tags is simply the above-explained method where a distance estimation is calculated to determine the alerting output. In a doorway zone, two tags will be placed in close proximity to one another, as seen in the figure. Ideally, the tags will be placed on the left and right boundaries of the doorway to simplify the algorithm. Both distances will be calculated to then be compared to a threshold value. As stated in the figures above, a summation may be done with these values to decrease complexity. A more sophisticated approach may be utilized to increase the accuracy. However, this may increase our reaction time and/or increase power consumption.

The alternative solutions for the system's operation are solely dependent on the alternative solutions for the subsystems. Alternative approaches for each subsystem are discussed in the "Solution: Subsystems" part of the report.

The team members agreed on several project objectives, which were then compared to determine the overall weight of each democratically. The comparison graphic can be seen in Figure 3.6 below.

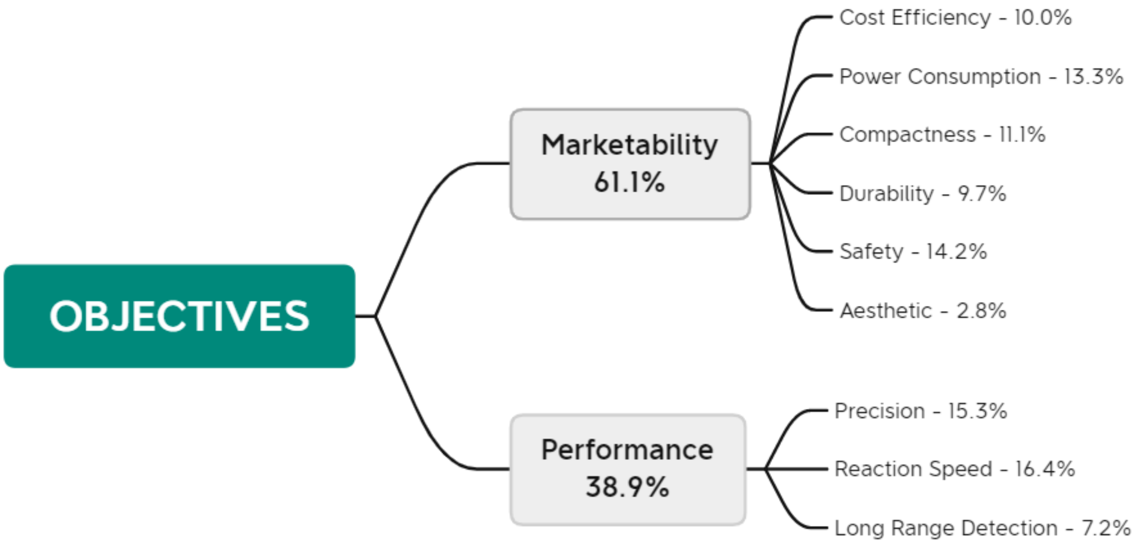

Figure 3.6 *Objective Weight Tree*

3.2. System-Level Flowchart

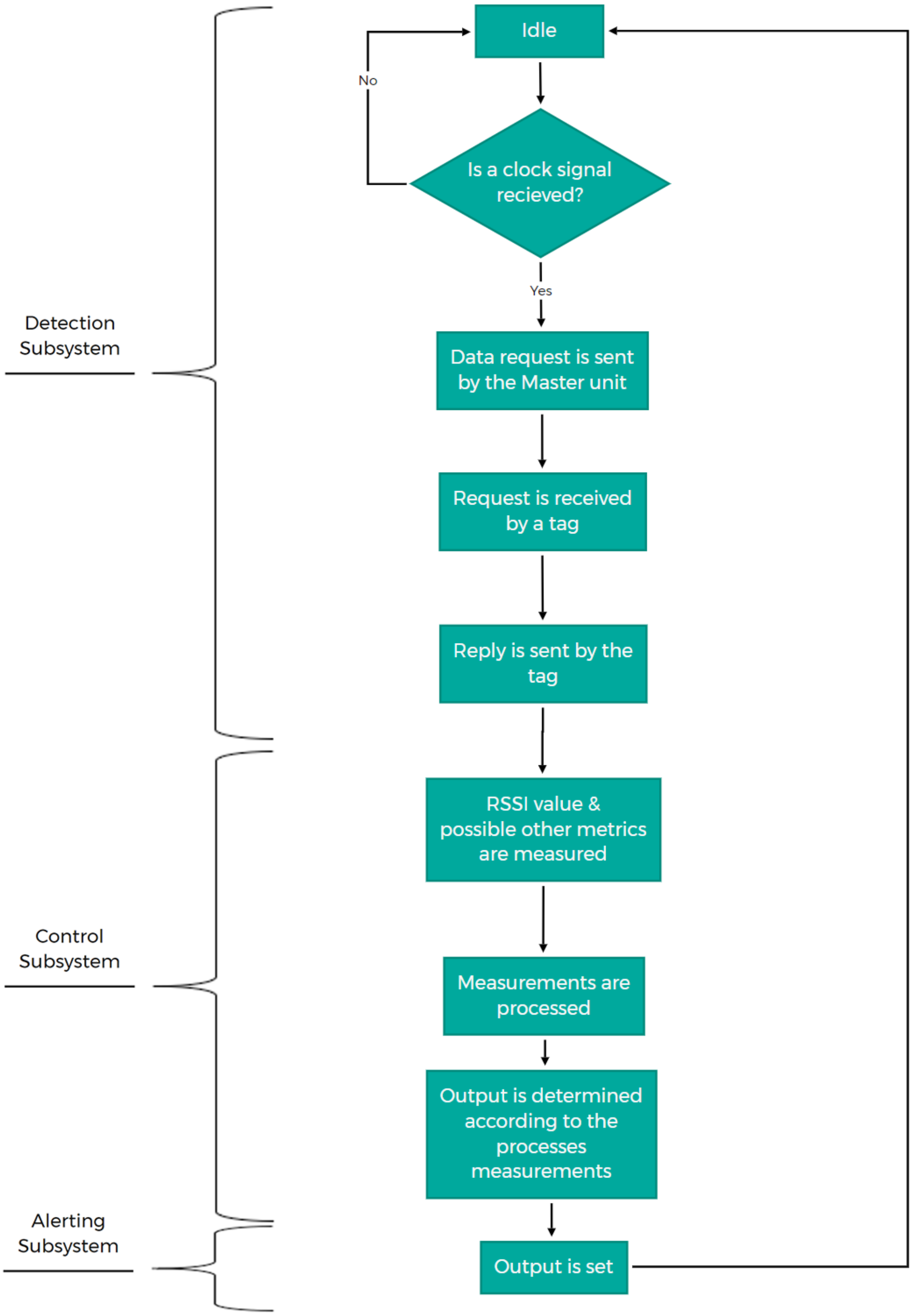

Figure 3.7 *Operational Flowchart*

3.3. Subsystems

The overall system consists of three subsystems, namely; the detection subsystem, the control subsystem and the alerting subsystem.

3.3.1. Detection Subsystem

The detection subsystem may be seen as the core subsystem of the project. As a generalization, the measurement taken by this subsystem should be correlated to the distance between the master unit and the tag. Furthermore, the measurement should not be affected by environmental conditions such as the angle between the antennas of the tag and the master unit as well as the objects in between them. Even if there is dependence between the measurement and the environmental conditions, this dependence should be relatively small in scale so that the operation of the system can be corrected using the software. In addition, the precision of these measurements must be good enough for our system to operate robustly. The data processing should result in a multi-level output according to the distance and be reliable in the sense that the generation of false-positives and false-negatives are minimal.

The research and development done before the module demonstration was focused on using RF communication in 2.4GHz and measuring the received signal strength indicator (RSSI) from each transmit-receive event. As explained in the "Control Subsystem" part of the report, the tag received a signal from the master unit and responded with another signal. The master unit then receives this signal to measure the RSSI value.

The control subsystem then processes the raw data through filters to eliminate the effect of noise and other undesired waveforms that have mixed in with the received signal. The result is the 'distance', or rather an approximation of the distance, which may then be discretized and passed on to the alerting subsystem to notify to the user the proximity of the two units.

The team finds it more intuitive to work on the zone tags first as determining the distance, or determining the distance interval, from the master unit to the tag will result in a working zone tag system. If we were to implement a door tag in the future, it might operate much similarly to a zone tag as the doorway can be considered a forbidden zone. If the master unit has to know whether the tag is a door tag or a zone tag, using more than one tag for the hallway at specific locations would allow us to differentiate between a zone and a hallway.

Note that many methods used in converting the RSSI value to the distance between the transmitter and receiver depend on an environmental parameter usually called “n”. This value is commonly given as an approximate value depending on the conditions and, for enhanced accuracy, should be measured for different positions in a specific environmental setup. As a result, the team decided to increase the measurement accuracy of the system initially to then be able to calculate the distance to some extent. Since our device needs to be wearable by a pet, the size of the antenna needs to be minimal. This creates a challenge as it requires the device to be optimized significantly. As a solution, the current setup tries to determine the distance interval that was predetermined using experimental results, not the exact distance. This simplifies the design without that much loss in practicality and cost-efficiency.

As alternative solutions, we may use some of the following protocols to enhance the operation of the detection subsystem.

Criterias\Methods	Passive RFID	Active RFID	Infrared (IR)	Wi-Fi positioning service (WPS)	Bluetooth	Ultrasound	Ultra-wideband (UWB)
Distance	1-5 meters	up to 100 meters	1-5 meters	around 10 meters	fewer than 10 meters	1-10 met+M13ers	1-50 meters
Accuracy	dm-m	cm-dm	m	dm	m	cm	cm-dm
Price							
Mobil Device Need							
Power Consumption							
Interference	water and metal	water or metal		wi-fi dead spots		walls and other solid surfaces	UWB signals are powerful and not prone to interference
Examples	access control, file tracking, race timing, supply chain management, smart labels	Automated toll collection	television remotes	wireless internet connection	mobile devices, headsets, computers, and other electronics	imaging human body, submarine	PC peripherals, wireless monitors, camcorders, wireless printing,
Notes	short-range, low cost, more durable	larger, heavier, expensive	low cost,		short-range	hard to use in noisy environments	high-risk, potentially high-cost

Figure 3.8 *Possible alternative protocols for the detection subsystem*

The tests done on the subsystem motivated the team to come up with alternative solutions that may be used alone, or incorporated into the current design to be used in conjunction with the current detection subsystem. In the following section, plan A will be the current detection subsystem, and the plans after will be the possible alternatives/additions.

Plan A: RSSI Measurement Using RF

The main plan is to use the current subsystem design as RF signals have less interference with objects as opposed to some of the other methods that will be described in the plans after this one. The team sees this as a major advantage. There may possibly be a change to the communication frequency if a more precise hardware option is available. If the algorithm used in the control subsystem requires more samples to operate, the sampling frequency may be changed, or the measurements may be stored in a data buffer.

As the reader may observe in the “Testing” part of the report, angle-dependency may be a problem for the final implementation. To combat this problem, a different antenna can be used in the master unit to have a more uniform measurement in terms of the angle between the antennas.

The environment parameter “n” seems necessary for converting RSSI to distance. However, the value is not easily obtained. A magnetization sensor and/or proximity (for solid objects) sensor can be used in the device to correct for or calculate this parameter.

Plan B: RSSI Measurement Using the Bluetooth Protocol

In the current design, the communication is done using a proprietary RF protocol and there may be advantages to switching to the Bluetooth protocol as the power of the received packet may be stored more accurately. The microcontroller used up to this point in the project supports Bluetooth, and more tests should be done in the same test cases (described in the “Testing” part of the report) to reach a conclusion about the feasibility of this approach.

Plan C: Time-of-Flight Measurement using Ultrasonic Sound

Unfortunately, the distances we are trying to operate in do not allow us to use a ToF based approach in an electromagnetic wave-based system due to how large the speed of light is. Available microcontrollers do not have enough timer speed to give us a meaningful measurement. As a solution, sound can be used due to it being slower to propagate. Similar to the RF-based system built beforehand, an ultrasonic transceiver unit may be implemented on both the tags and the master unit. The master unit will transmit a signal and wait for a response from any of the tags. Using the control subsystem's internal timers, the time between the transmit and receive events can be calculated. If one measures the amount of processing time in the tag before it sends a signal, ToF can be calculated. Moreover, assuming the propagation medium to be air results in an ability to calculate the distance.

The main disadvantage of such a unit is that sound waves travel at different speeds through different media, and they reflect off objects at a much higher rate. Thus, using a unit based on ultrasonic sound in conjunction with the RSSI measurements from electromagnetic waves and cross-referencing the values to have a more accurate system is a better option than using ultrasonic sound on its own. An entirely ultrasonic sound-based detection subsystem may still be implemented. To increase the accuracy of such a system, the control subsystem may have to do more processing to evaluate a discrete distance metric. However, more testing needs to be done to evaluate the feasibility of ultrasonic sound if it seems necessary.

3.3.2. Control Subsystem

For the control subsystem, the CC2640R2 evaluation board manufactured by TI was chosen, at least for the development stage. The board, developed to show the capabilities of TI's SimpleLink technology, has many features that allow communication over the air. These include proprietary RF, as well as Bluetooth Low Energy (BLE). The proprietary RF was the reason the board was chosen, although having BLE as well allows for easy implementation of a plan B in the case it is needed. While the project is being worked on the evaluation board, it is planned that we switch to a PCB design in the later stages of the development, using the CC2640R2 chip.

TI's open-source operating system TI RTOS was chosen for the operating system. TI also offers the EasyLink library, which allows for the easy manipulation of the proprietary RF function of the board. While the project's base consists of TI's open-source code written in C, these parts were abstracted away by coding a layer of C++ program on top of it. The program was written with object-oriented programming principles in mind; with output terminals such as UART and on-board LEDs abstracted through classes, as well as the RF transceiving capabilities of the board, which then produces the master and tag as separate classes who are inheritors of the same RF transceiver class.

The control subsystem is yet to be completed, and the existing parts of it were written for testing purposes and were showcased in the demonstration. In the current version, the system consists of two boards, one of them the master, and the other the tag. At start-up, the master transmits RF waves (at 2.4 GHz), and the tag searches for these waves. When the tag receives the signal, it acknowledges this by sending back a signal to the master. The master, on the other hand, upon the successful transmission of the message, switches into receiving mode to wait for the acknowledgment signal of the tag. When the signal is received, the master assesses the RSSI value of the received signal and processes it. It then prints the value through UART, as well as switches the onboard LEDs accordingly.

At first, a low pass filter was implemented to process the signal. As we process the data in real-time, to implement the low pass filter, LTA (long-term average) method was used. This method involves keeping the average value of all values received, with the last received value having a much higher weight than all the rest. The weight of the last value received, referred to as the filter factor, dictates the strength of the filter. The filtered value is found according to the equation:

$$filtered_t = raw_t * (1/filterfactor) + filtered_{t-1} * (1 - (1/filterfactor))$$

While the filter was successful at removing the noise when the tag was kept static, it was not very successful when the tag was in motion. To help solve this issue, the filter factor was made dynamic, with the filter becoming stronger when the values are changing rapidly, and vice versa. While this method gave better results, it still needed improvement. As such, a real-time implementation of a Kalman filter was made to test if it yielded better results. [1][2][3]

The Kalman filter is a filter widely used in signal processing. It involves predicting the next state of the signal using the previous state, as well as a Kalman gain, which depends on the uncertainty of the system. In many ways, it is actually similar to the previous filter used. However, some assumptions and simplifications were made to implement the Kalman filter in real-time while keeping memory limitations in mind. To simplify the formulas, it was assumed that the system was static. Furthermore, it was assumed that the uncertainty was correlated with the variance of RSSI. The following formulae were used to implement a watered-down real-time Kalman filter:

$$k = 1/(1 + variance)$$

$$y_t = y_{t-1} * (1 - k) + x_t * k$$

It can be seen that the philosophy from the previous algorithm was carried over. Some other variants of the given algorithm were also tested, which proved to have too low reaction times. The y in the equation is the output, the filtered data, while the x is the input. One thing to note is that since our filter is linear, the inputs must be as well. However, RSSI does not change linearly with distance, as we saw in our tests. And so, the input of the filter must be an intermediate variable that varies linearly. Since we want the output of the filter to be the distance, the input was chosen to be 'raw distance'; the distance value computed using only the raw momentary RSSI value, that is yet to be cleared of the effect of noise.

To transform RSSI value to distance, the log-distance pathloss model was used. This model approximates the relation between RSSI and distance as logarithmic, while including a reference RSSI value to normalize the correlation and integrating a signal propagation exponent, a constant whose value depends on the environment.

$$RSSI =- 10n * log(d/d_0) + A_0$$

In the equation, n is the signal propagation exponent, whose value ranges between 2 and 4 depending on the environment. d0 is any given distance, and A0 is the empirically found RSSI value at that given distance (100 cm was chosen for our case). n was also measured empirically through samples received in the control experiment. Bringing together these steps, we observed that the algorithm was able to compute distance in a controlled experiment.

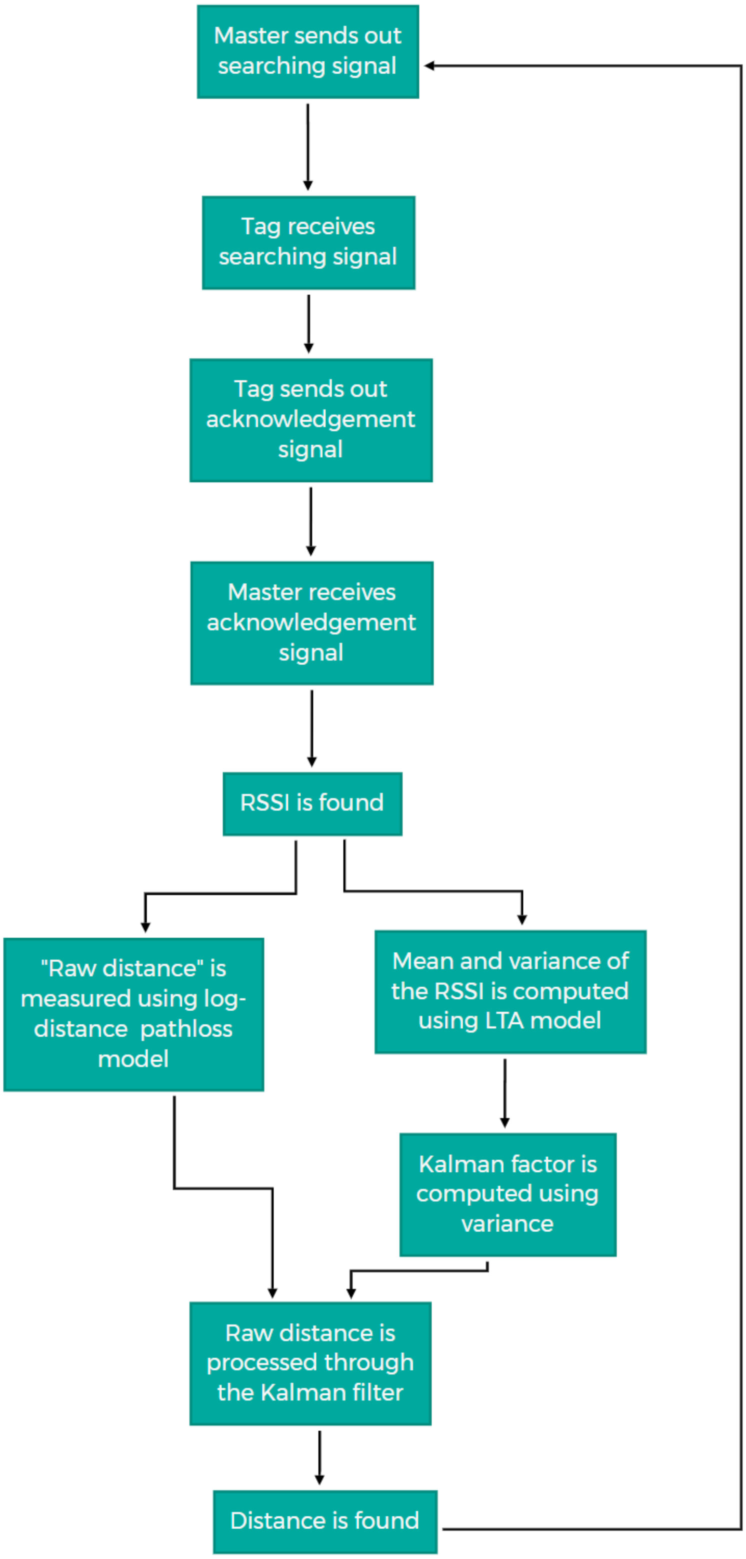

Figure 3.9 *Flowchart for the control subsystem*

While the current system works well under a controlled environment, problems with the system were identified. These problems cause the received RSSI values to differ from the expected results. They include magnetic interference and obstruction, angularity as well as rapid motion. To overcome these problems, other hardware and/or software solutions may be implemented. Currently, we plan to continue using the CC2640R2 evaluation board for development and then design our own PCB using the CC2640R2 microchip. Other microprocessors from TI's SimpleLink series, as well as microprocessors from the nRF series of Nordic Semiconductors were also reviewed and may be used in case CC2640R2 does not give the desired performance.

Other additions and/or changes may happen in the control subsystem according to the changes made in other subsystems. For example, an idea is that we could use a sensor to detect magnetic presence in the environment to dynamically compute the signal propagation exponent to improve robustness. Another idea is to employ more than one tag to make use of methods such as trilateration, which would improve the accuracy of the received RSSI values as well as the distance computation. Furthermore, while we are currently using the on-board LEDs to signify that the computed distance has changed, it is planned to use buzzers in the future, and the program will need to be changed accordingly.

3.3.3. Alerting Subsystem

The alerting subsystem should be effective enough to warn the pet about not entering the zone or not going through the hallway. However, it should also not compromise the composure of the pet. The signal should be appropriate in amplitude such that no harm is done. The current plan for the alerting subsystem and alternative plans are given below. Note that a combination of these methods may be implemented to benefit from each one's advantages or to mitigate the disadvantage of some of the implementations.

Plan A: Using Sound

The delivery of sound can be simply accomplished by using a buzzer and changing the frequency/amplitude of the signal. This seems appropriate as most people train their pets by talking to them in different tones and amplitudes.

If a more sophisticated design were to be implemented, a speaker can be used to play a specific sound file to deter the animal from moving into the forbidden zone.

Plan B: Using Vibration

The subsystem may also have a vibration unit to trigger the animal to back off from the forbidden zone. Driving such a unit would be very similar to driving a buzzer/speaker. Hence, the incorporation of this type of unit would be relatively easy.

Plan C: Using Light

By using an LED or another light source, a warning may be issued to the pet to deter their movement towards the forbidden zone. The brightness or the on/off frequency can be set easily. Again, implementing such a unit would be very simple compared to the other project parts.

3.4. Testing

There are three subsystems to be tested in the solution proposed for the project. These are the detection, control, and alerting subsystems. Up to this point, the detection system has been tested. The procedure followed during the tests of the detection subsystem, the results of tests, and the evaluation of test results concerning the requirements set for the detection subsystem are explained in the following sections.

3.4.1. Test Procedures

The team selected various test setups to observe the RSSI values for different distances between the tag and the master unit. As explained before, the master unit sent a signal that triggered a response from the tag. The RSSI value of the received signal was measured using the built-in tools of the CC2640 microcontroller. These cases were selected to test the angle-dependence and material dependence of the system specifically. For these tests, we used a simple low-pass filter to eliminate some of the noise in our measurements. In each case, the distance was set to 20cm, 40cm, 60cm, 80cm & 100cm, and a sample was taken for 10s with a sampling frequency of 10Hz. Using this 100-sample data, a mean & standard deviation value was calculated to observe the system's precision for each case and distance. To compare the effectiveness of the low-pass filter, a sample was taken using the raw value of the RSSI measurement without any loss of line-of-sight. Each test case and the measured RSSI value from a specified distance will be explained in the table given in the "Test Results" part of the report.

3.4.2. Experiments

The determined test cases are:

1. "Normal": The raw RSSI value is filtered & there is no object between the tag and the master unit. It is named as normal as it is assumed that the system would operate more reliably in such a case. Note that if not specified otherwise, all test cases used the filtered RSSI value.
2. "Chipboard": A chipboard with a thickness of 2.5 cm was placed 10 cm away from the master unit, in between the tag and the master. This case was chosen to determine what changes a furniture-like obstruction would create.

3. "Metal": A nonstandard iron object with a complicated shape was placed in the line of sight to evaluate its effect.
4. "Angle90": The tag was rotated 90° on the same plane as the master unit to observe the effects of angle.
5. "Angle180": Similarly, the tag was rotated 180° on the same plane as the master unit to observe the effects of angle.
6. "RawRSSI": This case is simply the "Normal" case without filtering. It was created to observe what level of deviation we were getting from our measurements.

The photos of the tests made with the detection subsystem are shown in the following figures.

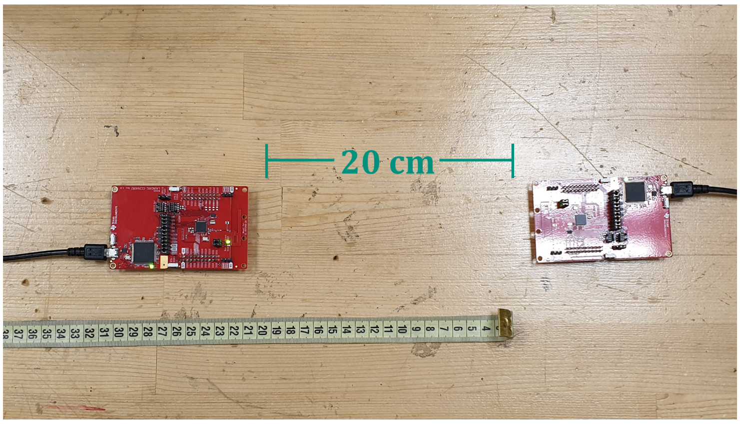

Figure 3.10 *Photo of the setup*

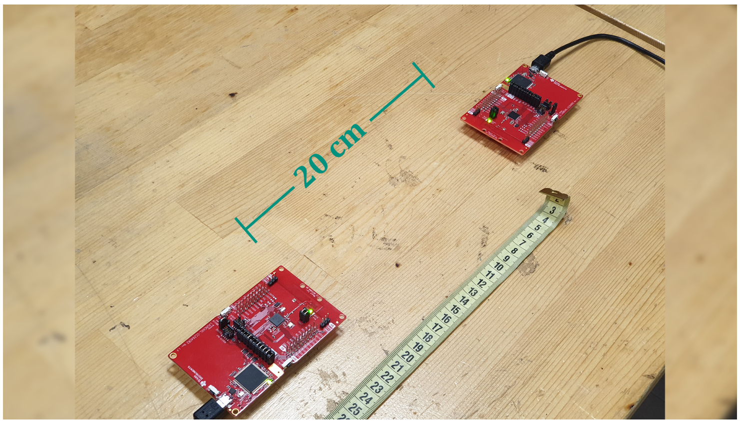

Figure 3.11 *Another photo of the setup*

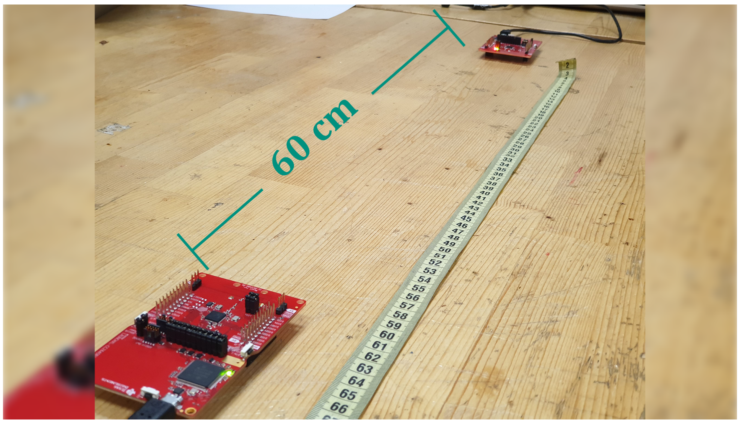

Figure 3.12 *Normal case with 60cm*

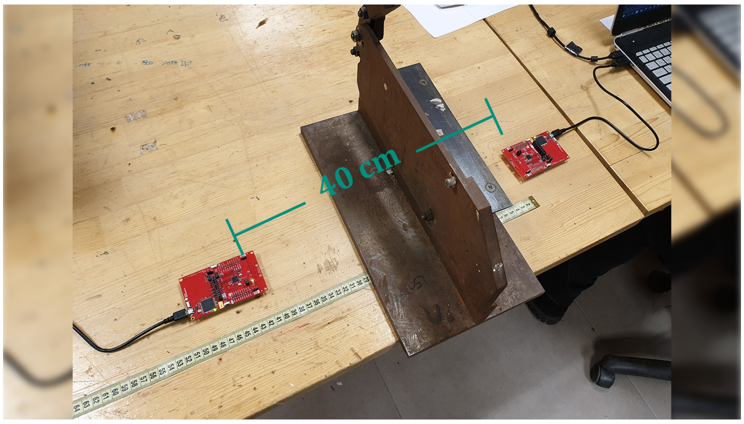

Figure 3.13 *Non-Uniform Metal 40cm*

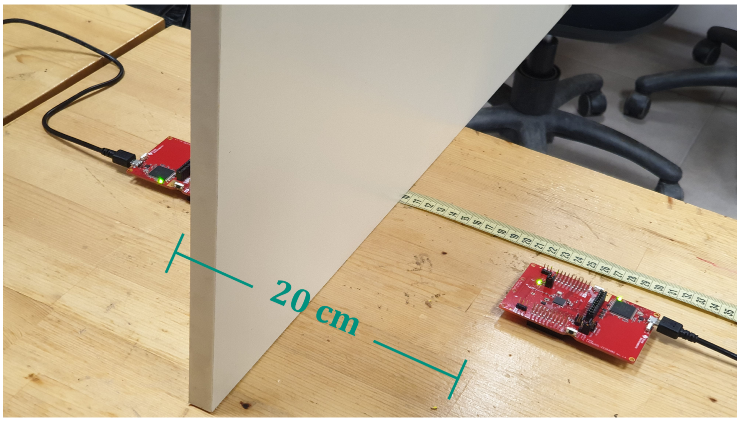

Figure 3.14 *Clipboard 20cm*

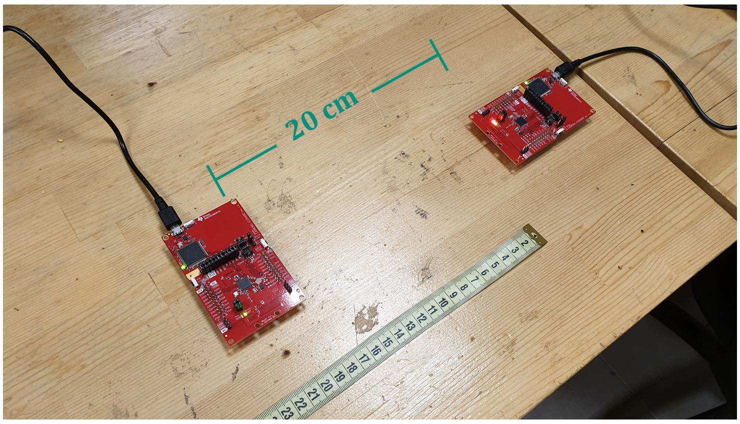

Figure 3.15 *90° Angle 20cm*

3.4.3. Test Results

	Mean RSSI (dBm)					**Standard Deviation of RSSI**				
Distance(cm) / **Type of Test**	**20**	**40**	**60**	**80**	**100**	**20**	**40**	**60**	**80**	**100**
Normal	-27.96	-31.41	-37.46	-38.19	-45.05	0.034	0.187	0.404	0.206	0.749
Chipboard	-26.6	-29.37	-31.17	-34.01	-49.15	0.107	0.088	0.258	0.0308	0.176
Metal	-41.26	-35.01	-49.45	-48.32	-46.65	0.314	0.509	1.532	3.64	0.318
Angle90	-33.9	-37.9	-46.04	-51.57	-44.24	0.532	0.559	1.17	0.717	0.548
Angle180	-27.71	-33.85	-36.95	-39.91	-37.79	0.09	0.131	0.107	0.127	0.197
RawRSSI	-30.64	-33.83	-34.4	-37.71	-43.52	0.52	0.425	0.616	0.475	0.842

Figure 3.16 *Test Results*

Note that the values colored in red were deemed to be unreliable as for each time they were sampled, the result changed by at most 30%, and because of this, they were treated as a failed measurement. A linear approximation of the normal case (filtered & unobstructed) is given below.

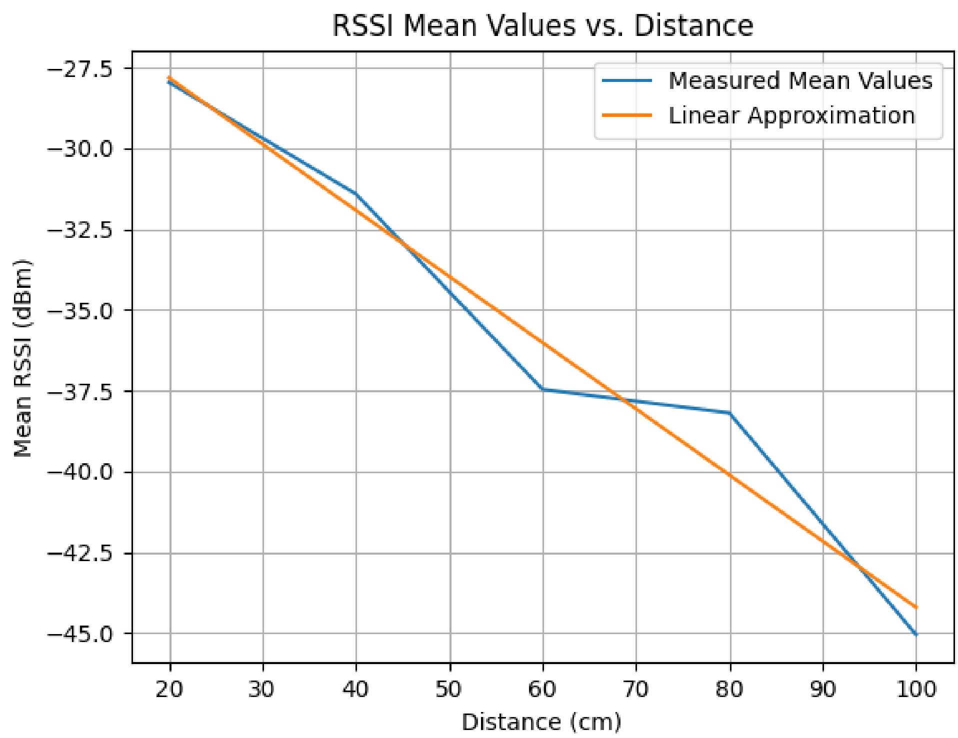

Figure 3.17 *RSSI mean values vs. distance plot for the "Normal" case*

A linear approximation can be used due to the range of the distance we operated at. Since the range is much smaller than the expected maximum range of the transmitter unit, local values can be approximated linearly. For a larger range, this is invalid.

The linear approximation turns out to be $y\ (dBm) = -0.2048 * x\ (cm) - 23.726$. We would expect the result to be more correlated to the linear approximation in this short distance range. However, the practical application deviates from theoretical assumption since the medium of propagation is non-uniform in terms of its electromagnetic properties.

If we were to approximate the “Chipboard” case linearly, the resulting line would be $y\,(dBm) = -0.2487 * x\,(cm) - 19.138$. This was not expected as we thought that in the “Chipboard” case, the measured RSSI values would be lower for close distances. Our test results showed that in close proximity, the “Chipboard” case resulted in higher RSSI measurements, and as the distance increased to 100cm, the measurements were below the “Normal” case. Note that the RSSI dropoff per distance is higher in the “Chipboard” case. As a result, the conclusion of “RSSI values would decrease faster if there is an obstruction” can be reached. However, we cannot conclude that an obstruction would imply lower RSSI readings.

The comparison of the cases “normal” (filtered & unobstructed) and “metal” (filtered & obstructed by an iron object) is given in the following plot.

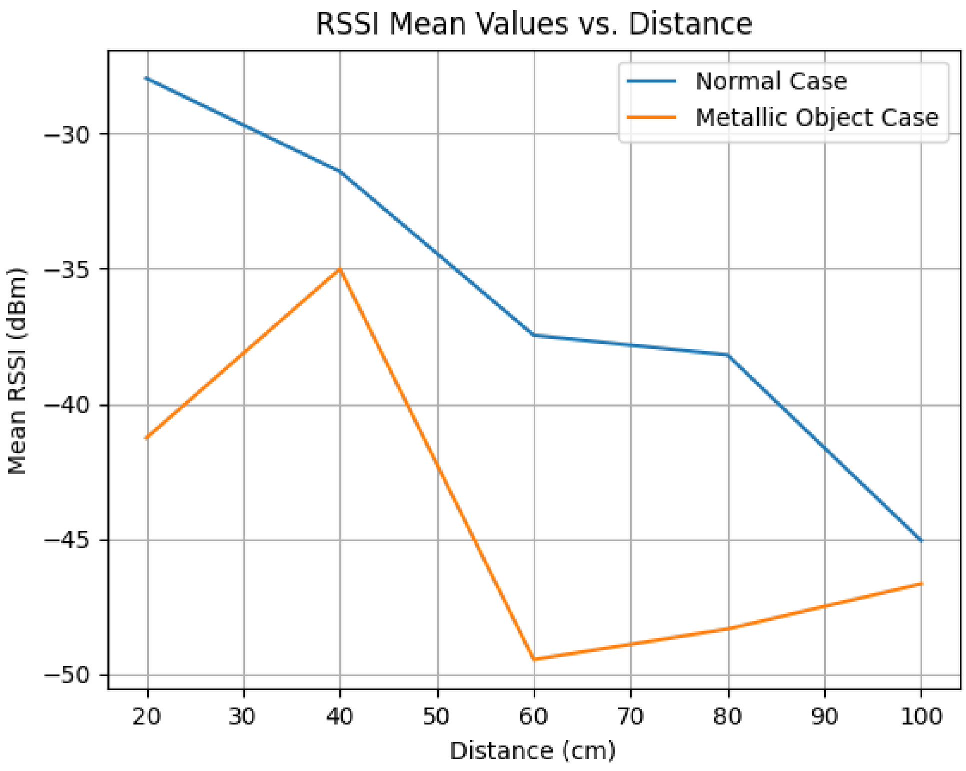

Figure 3.18 *Comparison of the “Normal” case and the “Metal” case*

The existence of a metallic object in between the tag and the master unit changes the measurements by at most 47%. Moreover, the assumption of “RSSI will strictly decrease as distance increases" is not valid for the metallic object case.

The standard deviation of the samples taken in cases normal (filtered & unobstructed), raw (not filtered & unobstructed), and metal (filtered & obstructed by an iron object) are given below.

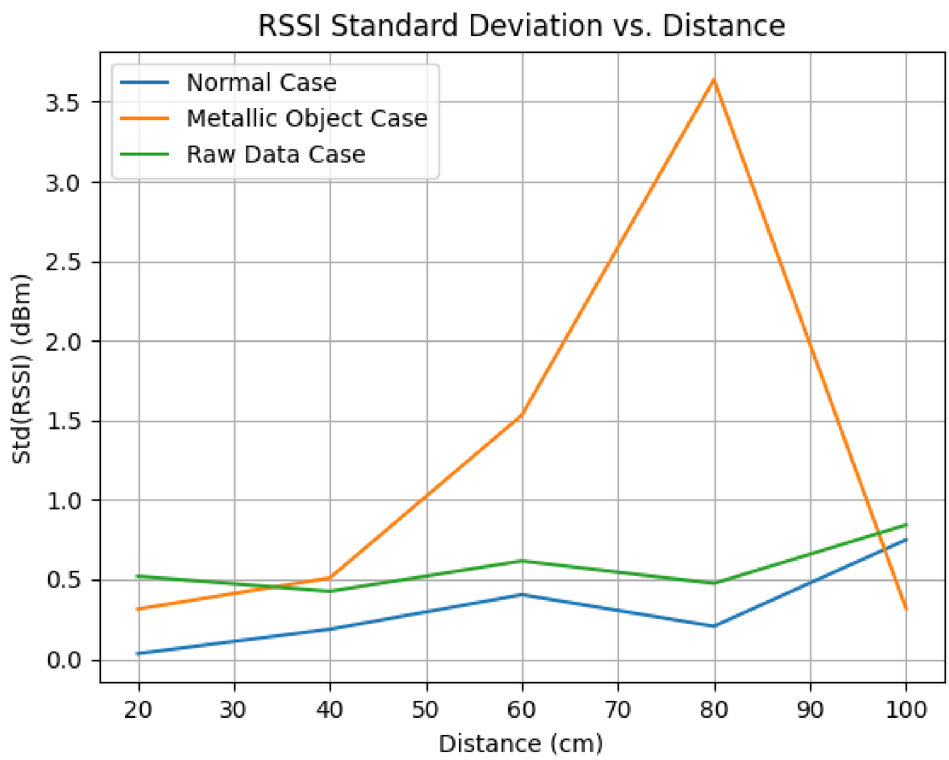

Figure 3.19 *Comparison of standard deviation values for the given cases*

As you can see, the standard deviation value of the "metal" case is at most 15 times the "normal" case for the samples taken. This implies that the value of RSSI was comparatively more unstable compared to other cases.

If we compare the raw and filtered (named as normal) cases, as expected, the filter decreases the standard deviation.

For the angled cases (named "Angle90" & "Angle180" for 90° and 180° respectively) the samples were sensitive to minimal angle changes as a change of approximately 5-10° resulted in a change in the RSSI value of about 2-3 dBm.

This made the team less confident about the validity of measurements as such small changes of angle cannot be determined reliably for each measurement.

As a simple demonstration, a simple distance calculation algorithm was implemented. The threshold distances were set as 40cm, 70cm & 100cm.

Set Threshold Distance (cm)	Measured Threshold Distance (cm)	Error (%)
40	48	20
70	76	8.57
100	98	2

Figure 3.20 *Table for the comparison of expected and measured distances*

The error is within our error margin. As the distance increases between the tag and the master unit, the proportional error increases in the test we have done. Since the error is lower in larger distances, using the more accurate measurement, an algorithm may be able to correct for the deviation at smaller distances assuming the pet starts moving from larger distances towards the tag.

4. Plans

The prepared project needs improvements for its system requirements, functional requirements, and customer-oriented developments. Currently, the device is in the prototype stage, with the skeleton of its functions put in place but lacking refinement. Tests of the prototype were conducted, and were presented in the section prior. In June, the final product will be ready for its customer-oriented presentation at the KKM Project Fair. Until then, the project needs to be developed to the point where all subsystems work as desired.

4.1. Management

The management organization of the team, that is, the responsibilities of team members, the Gantt Chart to be used during the planning, estimated cost analysis, and deliverables are provided below.

4.1.1. Distribution of Roles

Teamwork and planned working-system are required to complete the project on time. For this, as stated in the Business Report, our team members' planning for future jobs will be as follows:

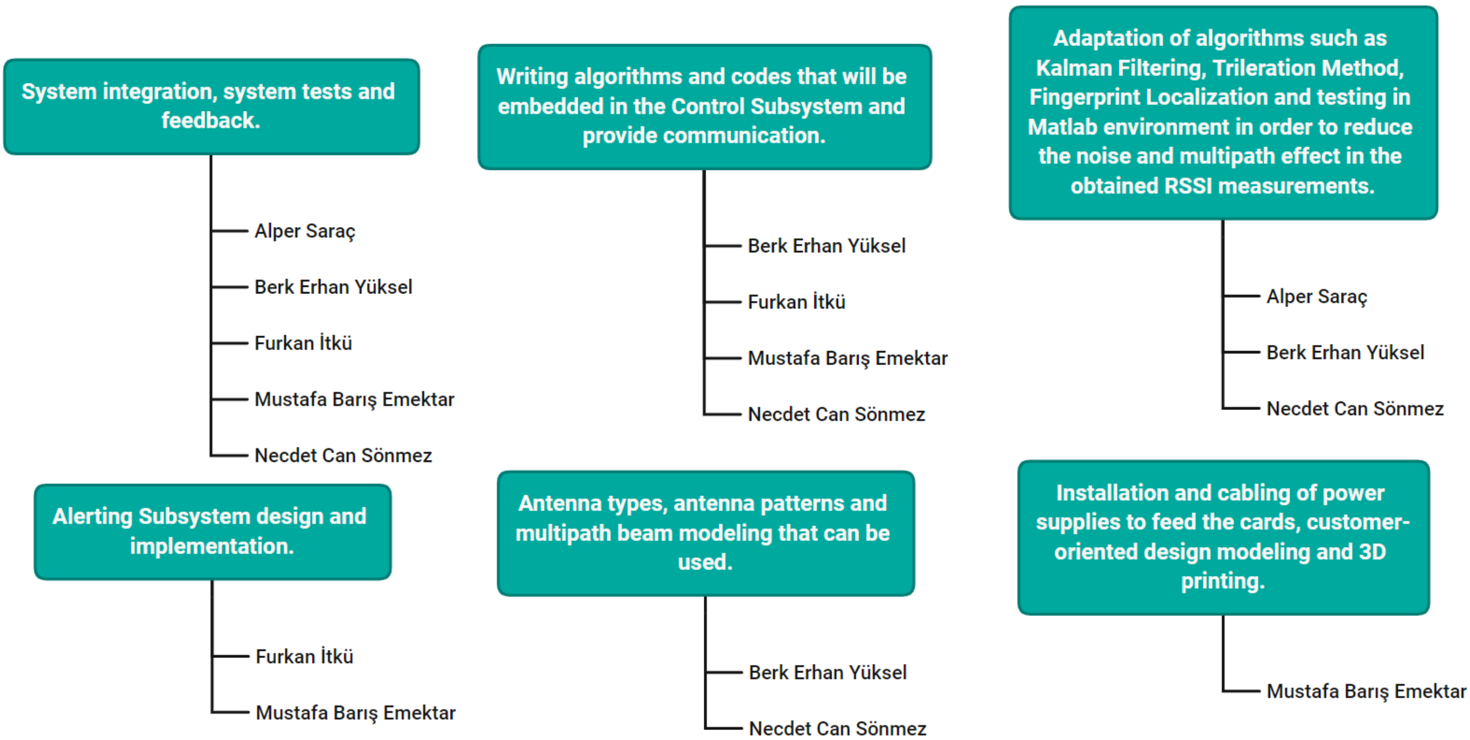

Figure 4.1 Chart of *different tasks and responsible members*

The Gantt Chart for the allocation of tasks and time periods will be included in the appendix for readability.

4.1.2. Cost Analysis

Items To Be Used (*)	Subsystem	Number of Pieces	Costs(**)
Microcontroller "CC2640 Evaluation Board Texas Instruments"	Control & Detection	1	29 $
Tags "CC2640 Microcontroller- Texas Instruments"	Detection	3	8.85 $
Power Supply "Button Battery – 3.3V"	Control & Detection	4	8 $
Buzzer	Alerting	1	0.20 $
Sticking Device (for Tags)	Control & Detection	10	0.72 $
Wearables for Animals "Simple Collar"	Control & Detection	1	2.82 $
TOTAL			49.59 $

Figure 4.2 *Cost analysis table for the current setup*

(*) (Expected Items) The equipment examined and used here may change according to our future research and test results. There may be some materials that can be used as extra or removed from there.

(**) Pricing is based on known market value of the components (Robotistan, Alibaba, etc.). It may change according to the incoming hikes or discounts.

4.1.3. Deliverables

While determining our deliverables needs for a customer-oriented project, it was important for us to put a product that met the system requirements. For this, the following plans were made:

Equipment Deliverables

I. **Master Unit:** A structure suitable for the average size of the animal to be attached, wearable, able to stay in contact with the tags thanks to the kit it has on it and giving stimulation to the animal according to the signals it receives from the tags. On it, there is the microprocessor, antenna, and power supply feeding the card and buzzer.

II. **Tags:** Tags that the customer will place in the desired part of the house with a sticky apparatus for the restricted area and the prohibited doorway.

Service and Technical Hardware Support

I. **Warranty Certificate:** The device is guaranteed by Lambda Company for two years. In case of faulty use by the customer and the system is opened by any third party from outside, the warranty will be voided.

II. **User Manual:** A user-friendly document stating the device's initial setup, recommended usage patterns, and modes.

4.2. Test Plans

There are three subsystems that make up the device, each of which needs to be tested. Of these, tests were carried out for the detection subsystem in the laboratory, and the results were also presented live during the demo. These tests demonstrated the acquisition of the RSSI value, which is the main metric the algorithm uses for estimating the distance between the master and the tag. However, there are more tests that need to be carried out to ensure that the device functions as desired. Some of these test plans are given below.

4.2.1. Test Plans for Different Antennas

The team plans to obtain different antennas to compare the measurements taken from different distances & angles. We think that the project is heavily reliant on the antenna choice as the received signal strength is dependent on it. These antennas will be connected to the master unit and/or tags to obtain varying data samples for different cases.

4.2.2. Test Plans for Doorway Tags

The implementation of doorway tags will require us to obtain more microcontrollers to design more tags as our current doorway tag system is reliant on more than one tag. We plan to determine the doorway using two tags placed at the boundaries of the doorway. To be able to determine the feasibility of such a system, it should be tested extensively.

4.2.3. Test Plans for Alerting Subsystem

The different options for the alerting subsystem were explained in the "Alerting Subsystem" part of the report. Components for different options (LED, buzzer, speaker) will be obtained and tested as they are cheap compared to other components used in the project. The effectiveness of each system design will be evaluated according to our objectives, such as low power consumption and low cost.

4.3. Integration of the Sub-Systems

The detection subsystem, which works through RF waves, is integrated within the microprocessor that we use (CC2640R2). It is controlled by the control subsystem, which represents the program embedded within the microprocessor. The alerting system is currently the onboard LEDs, planned to be replaced with a buzzer. In any case, the alerting subsystem is controlled by the control subsystem by the pin connection of the microprocessor.

The detection subsystem is tasked with transmitting and receiving RF signals. The detection subsystem is controlled by the control subsystems of the master unit and the tag, who command the master unit and the tags to exchange signals between each other to communicate. The received signals are processed by the control subsystem of the master unit, which tells the alerting subsystem to light the two LEDs in four different configurations according to the estimated distance between the two devices, which it computes using the received RSSI. It is planned that the LEDs be replaced with a buzzer, whose voltage input will be controlled by either current modulation or PWM of the assigned pin to infer the wearer of their proximity to the tag.

4.4. Foreseeable Difficulties

As stated in the alternatives of each subsystem, many other methods can be incorporated into the current design to satisfy our requirements. Some of the possible problems and contingency plans associated with them are given below.

Contingency plan for a modeling failure

If the modeled operation of the detection subsystem and its practical output do not match, alternative plans described in the “Detection Subsystem” part of the report will be implemented to test whether the other methods result in a better result.

If the results are still below our accuracy goal, a comprehensive data set that contains data from many cases will be created to interpolate the output. The algorithm may be a probabilistic one, comparing the measurement with the dataset to guess the distance interval, or a piecewise linear approximation to name a few of the options available. There may even be the utilization of machine learning to estimate the parameters of a general measurement to the output function. The exact algorithm for any of the possibilities will be determined according to the specific case of the possible problem. Hence, the exact details of an algorithm are not determined for this contingency plan as it is case dependent.

Contingency plan for extreme angle dependence

The current design utilizes a built-in antenna to transmit and receive RF signals. If the properties of the antenna result in a system where the angle of the master unit with respect to the tag affects the measurements to the extent that reliability is below our criterion, different antenna designs will be used to eliminate angle dependence. If the measurements are still not accurate, each tag may contain more than one antenna at different orientations to take measurements from different angles. This may correct the effects of angle dependence in the system.

Contingency plan for environmental condition dependence

The received signal strength of electromagnetic waves is dependent on various properties of the materials in the medium in which they propagate. As an example, ferromagnetic materials change the measurements quite drastically. Placing the tags in the forbidden zones restricts the system in the sense that different indoor environments will have various objects that may interfere with the received signal in previously unknown ways. Most of the methods that calculate distance using RSSI have an environmental parameter commonly named “n” and it is usually experimentally calculated in a uniform medium.

If the variance of “n” is too high so that the accuracy is below our goal or a solution that has accuracy above our requirements cannot be reliably obtained for freely placed tags, the team may choose to have the tags in specified locations to use a position detecting system that may utilize a trilateration algorithm.

As a different solution, a magnetization sensor may be incorporated to correct for the magnetization of the materials in the propagation medium.

Contingency plan for failed implementation of doorway tags

The current plan is to have more than one tag at the doorway entrance to classify the tags as doorway tags internally.

If the use of many tags results in an overly complicated system or an inaccurate system, different technologies such as IR distance detectors may be used to determine the state of a tag. As another alternative, trilateration methods can be implemented in the control subsystem to increase the accuracy; hence, allowing the use of multiple tags in close locations to be detected as doorway tags.

If all of the above fail, zone tags can be used as doorway tags, as placing a tag close to a doorway will result in it being a forbidden zone. This is, of course, assuming that using such a system will not decrease the practicality or the accuracy of the product.

5. Conclusion

The currently implemented solution to the problem was presented in detail, along with the results of the tests conducted on the prototype. This solution utilizes RF waves to allow two units (master and tag) to communicate and for the master to compute an estimate of the distance between itself and the tag through the RSSI value. The master then switches the onboard LEDs to infer the observer of the current state of proximity between the two units. The tests conducted show that the prototype is able to deduce the proximity between itself and the tag with relatively good accuracy in the scenario where the two units face each other perpendicularly with no obstruction. The cases where this is not true were also explored and identified as possible risks to lowered accuracy.

Also, plans on how the prototype will be improved further were presented, such as switching from evaluation boards to designed PCBs, as well as implementing a buzzer to replace the currently used LEDs. Furthermore, alternative plans that may be implemented in the case that the current implementation does not work as desired were discussed. These included employing methods such as trilateration or magnetic sensoring to improve the robustness of the device.

In the report, the project to be implemented was introduced, as well as the proposed solution to the given problem, along with alternatives. The proposed solution was analyzed on the subsystem level, and foreseen features to be implemented were talked about. The current progress of the project was detailed, and test results conducted on the prototype device were presented. Scenarios that may pose a risk of lowered accuracy were identified, and contingency plans on how to fix these problems were given. Other details on the project, such as the organization of the group to manage the project, expected expenditure, a Gantt chart of the planned timetable, and expected deliverables were also presented.

6. References

[1]https://www.wouterbulten.nl/blog/tech/kalman-filters-explained-removing-noise-from-rssi-signals/

[2]https://www.researchgate.net/publication/261156571_Real_time_RSSI_error_reduction_in_distance_estimation_using_RLS_algorithm

[3]https://www.researchgate.net/publication/317150846_Radio_Frequency-Based_Indoor_Localization_in_Ad-Hoc_Networks

7. Appendix

7.1. Gantt Chart