MIDDLE EAST TECHNICAL UNIVERSITY

Electrical & Electronics Engineering Department

EE494 - Engineering Design II

"Cısss!"

Final Report

Company Name: Lambda

Starting Date of the Project: 18.10.2021
Completion Date of the Project: 15.06.2022
The Project Duration: ~ 8 Months

Members of Company:

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1. Introduction

Many people own pets in their houses nowadays. People treat their pets as if they were children, and they do not keep them separate from their families. On the other hand, these pets may be as naughty as they are cute at times. They might leave the house by going out the front door, or they could climb the kitchen counters to eat something they should not. Therefore, by preventing these misbehaviours, pet owners need a tool to keep their pets from injuring themselves or creating a mess. This is where Lambda comes into play.

Lambda is proud to present a revolutionary product that aims to prevent pets from engaging in potentially dangerous behavior. The offered product is meant to be worn on the pet's collar, but due to the device's tiny form, clients may have their pets wear it anywhere they choose. The main device, referred to as the "master unit," is designed to be as small and light as possible to avoid causing discomfort to the wearer. The master unit, however, is not the only component of the product. The product also comes with tags that can be placed wherever in the house that the user wants to mark as "forbidden." If the pet trespasses or approaches certain prohibited areas, the master unit will alert the pet without harming it. The owner can place the tags on the boundaries of a doorway to deter the pet from passing through that doorway. The alerting mode is acoustic. The master unit alerts the animal using sound. Given that thousands of pet owners deal with the concerns listed regularly, it's obvious that a device that can prevent harmful behavior in animals without injuring them has enormous market potential.

The document you are going to read is the product's final state, which is a technical report ensuring that the system is complete and practical. The subsystems of the device, the tests done with the system and its specifications will be elaborated on in their sections.

1.1. Company Organization

Lambda Company was established in October 2021 at METU, Ankara.

Innovative
Technological Development
Creative
Reliable
Energy-efficient
Environmentally
Human-friendly

Mission

To provide innovative, reliable products and energy-efficient solutions in the field of electronics and system integration, and to make people's lives easier with the projects it produces.

Vision

To be a reliable, innovative, environmentally and human-friendly technology company that maintains its sustainable growth with the values it creates.

As the project requires work from different areas of engineering, the team members are also competent in different areas themselves. Lambda consists of 5 prospective engineers who have experience in various fields. The members have a high sense of responsibility and teamwork and understand the importance of cooperation to achieve success. The academic background of the employees, their areas of expertise, their experiences, as well as their roles and responsibilities within the project are given below:

Berk Erhan Yüksel	Necdet Can Sönmez	Mustafa Barış Emektar	Alper Saraç	Furkan İtkü
- Signal Processing - Algorithm Design - Matlab, C/C++	- Computer - Embedded Systems - Python, C/C++	- Computer - Embedded Systems - C/C++ - 3D Modeling & Design	- Computer - Embedded Systems - Python, C/C++/C#	- Computer - Embedded Systems - Matlab, C/C++

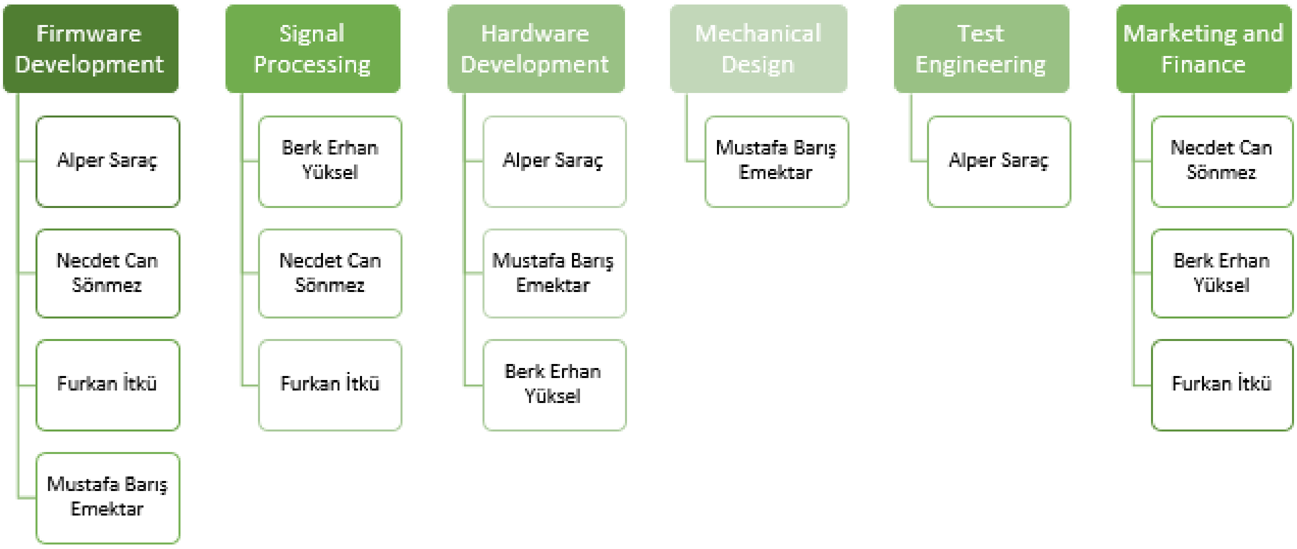

Figure 1.1 Company Organization Chart

2. Executive Summary

"Cısss!" is the name of the product that will be presented. It is smart equipment that aims to make pet parents' lives simpler. The device is made up of two parts: a master unit and a number of tags. The master unit is a wearable smart gadget that detects the presence of tags nearby and warns the wearer (the pet) of any misdeed. To "mark" it as forbidden, the tags can be put in open spaces as well as entrances up to 90 cm wide. The device notifies the pet when it approaches the restricted zone without harming it. The master unit is small and safe for the animal, causing no discomfort or injury.

The built system has two (or more) devices interacting using radio frequency wave radiation, and the master unit calculates the tag's distance using the wave's received signal strength indication (RSSI) value. The estimated distance is used to determine “the state of proximity” of the master and the tag. The wearer is warned (if necessary) of their proximity level to the forbidden point through acoustic feedback. This feedback becomes more and more disturbing (becoming higher in pitch) as the wearer’s proximity level increases.

This report presents how the solution to the problem was implemented. The system designed for the implementation is presented in a top-down approach, with the entire system given first and then the details about each subsystem being given next. The strong and weak points of the design are talked about, backed up by the appropriate tests and numerical data. The test procedures followed by cost and power consumption analyses of the system, as well as the expected deliverables can also be found in the relevant parts of the report.

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3. Design Description

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 **exact** solution methods. In each section, the respective subsystem is explained in detail.

As indicated in the above sections, the company's aim was to design a compact, low-cost product with low power consumption. However, there had to be a trade-off between these objectives. Therefore, the company's determined specifications and their justifications 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 is 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 (enclosure) **dimensions are 7.7cm x 6.7cm x 1.7cm for each unit**. The enclosure design for both the master and the tag is shown in Figure 3.1.
- Since the device's wearer is a pet, it should not weigh over 100-150 grams. Fortunately, the final product **weighs 75 g for each unit** which brings high mobility to the product.

- Both the master unit and the tags are powered by a single-button **battery**, which is relatively small and accessible.

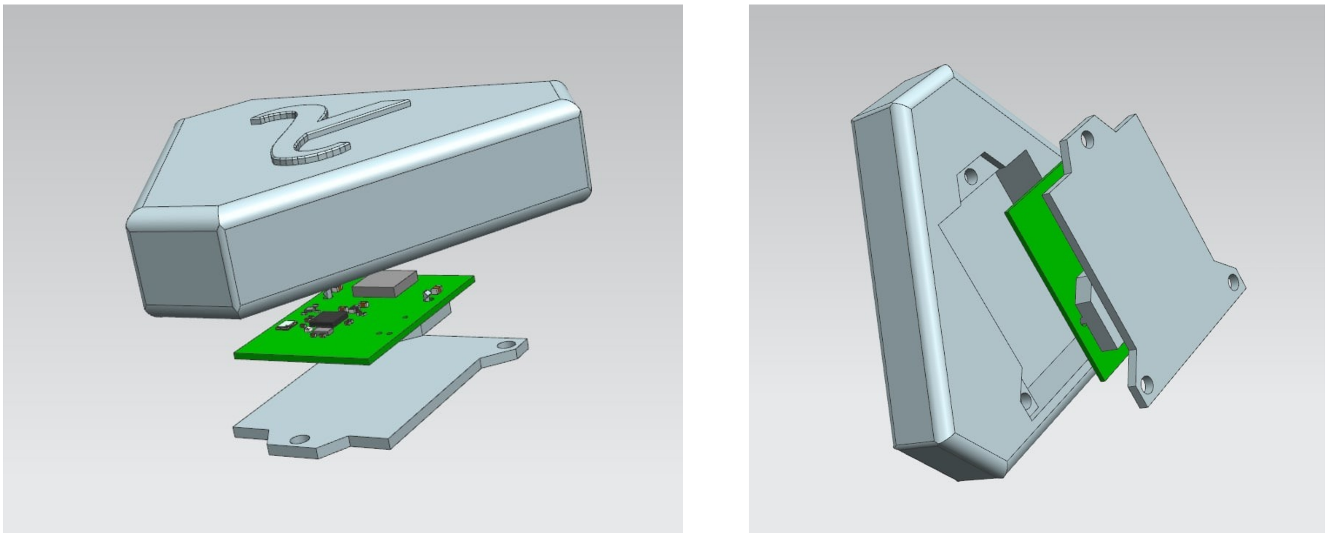


Figure 3.1 *The 3d model of the master unit and tag cases*

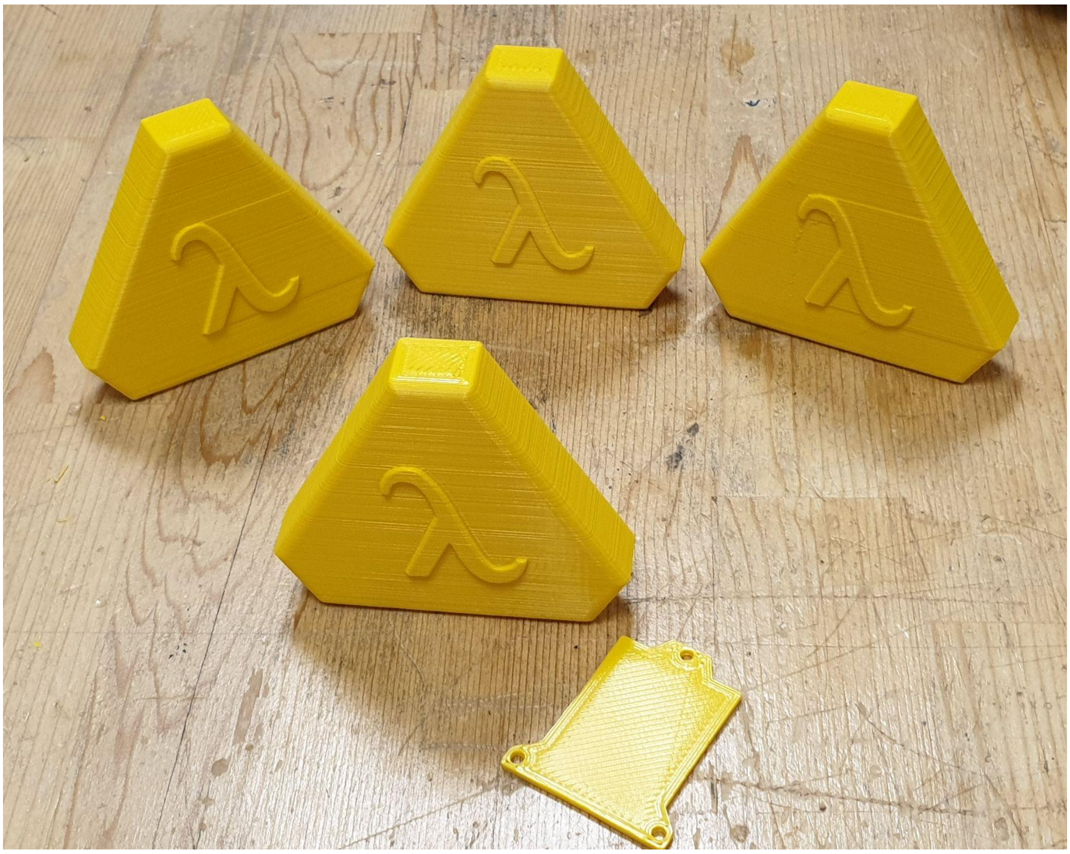


Figure 3.2 *The printed master unit and tag cases*

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.

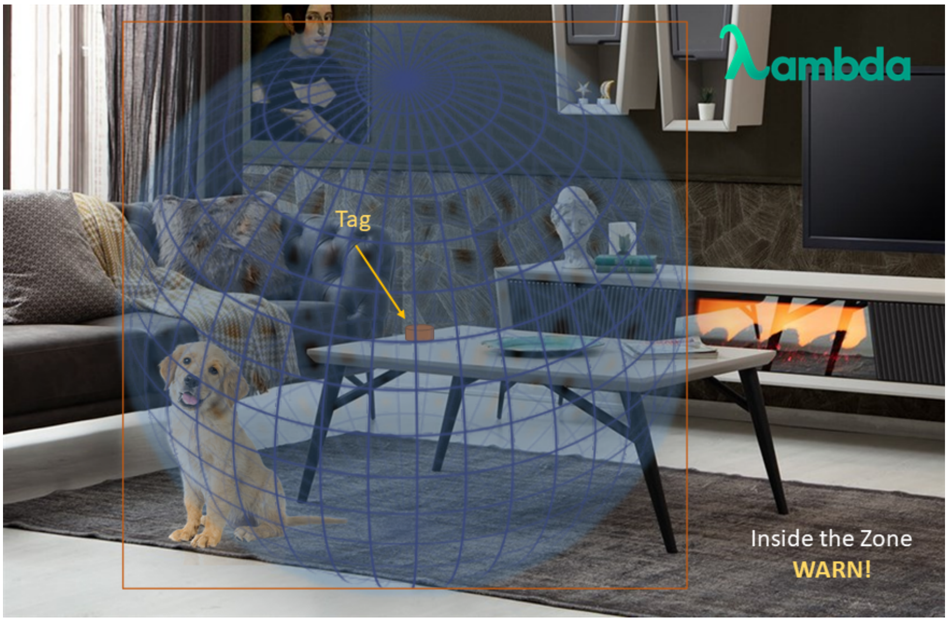


Figure 3.3 *Representation of the animal being inside the forbidden zone*

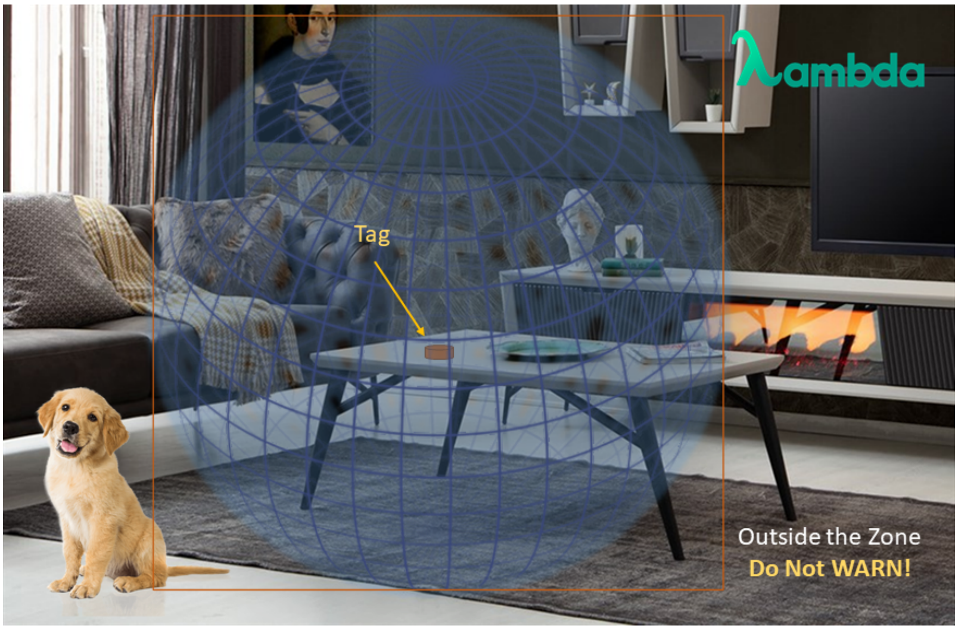


Figure 3.4 *Representation of the animal being outside the forbidden zone*

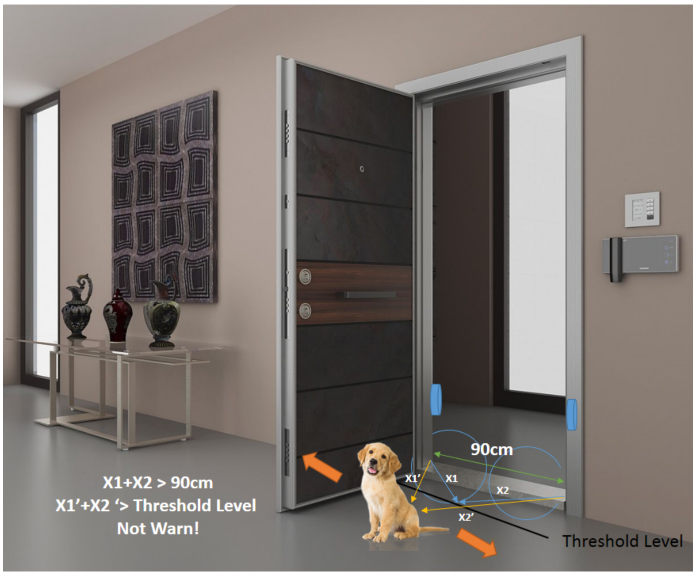


Figure 3.5 *Door tag explanation*

Figure 3.6 *Explanation continued*

$$X_1 \, and \, X_2 : \, Angular \, distance \, of \, two \, tags \, to \, the \, specified \, threshold \, level$$

$$X_1' and \, X_2' : \, Angular \, distance \, of \, two \, tags \, to \, the \, main \, tag \, (pet)$$

The figures above show our design of differentiating a forbidden doorway 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, two tags will be placed in close proximity to one another, as seen in the figure. Ideally, the tags should be placed on the left and right boundaries of the doorway. Both distances are calculated to then be compared to a threshold value.

3.1. System-Level Flowchart

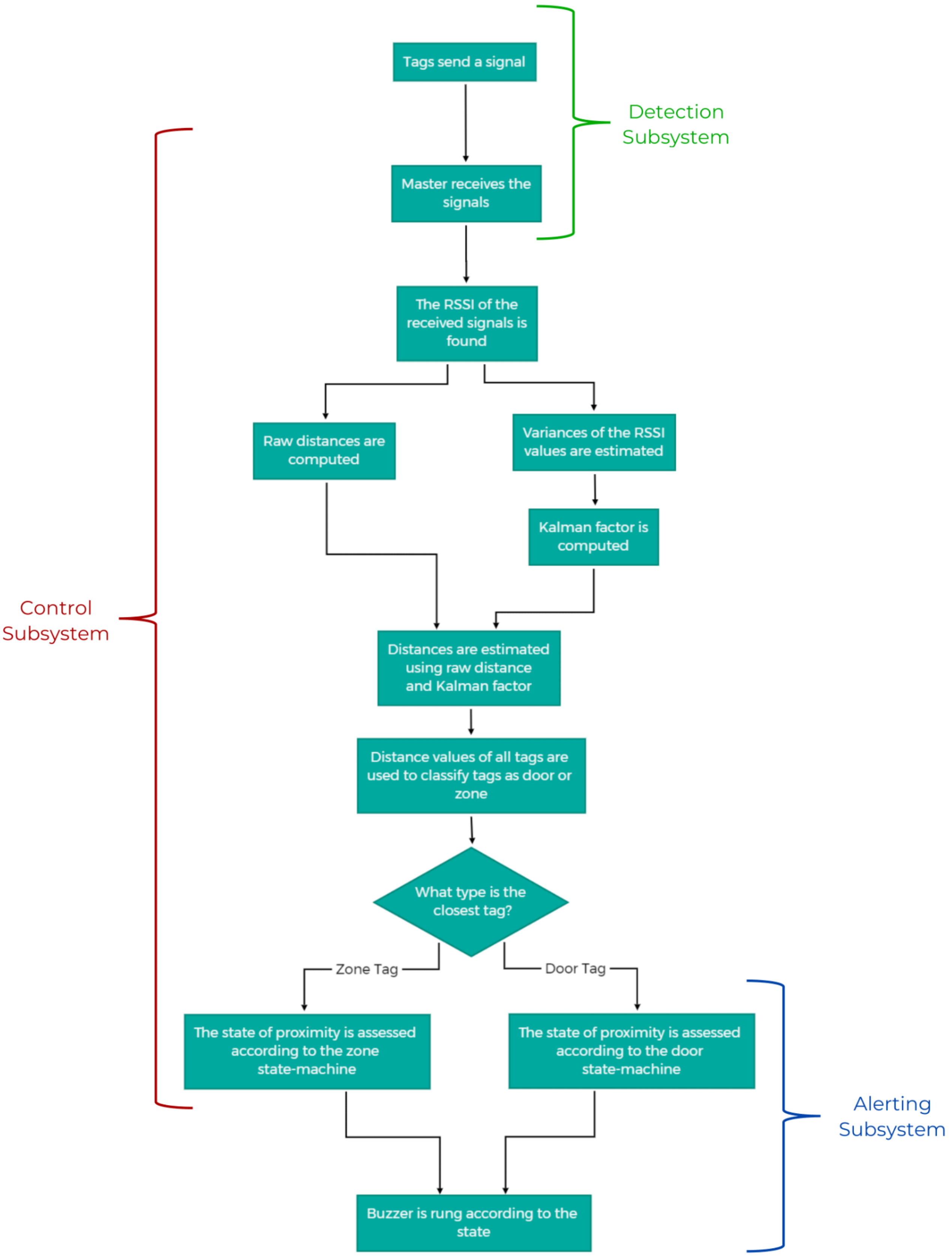


Figure 3.7 *Operational Flowchart*

3.2. Subsystems

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

3.2.1. Detection Subsystem

In the prior reports, the detection subsystem and its operation were mentioned. In this report, the specifics of our application will be presented.

The previous research and development 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 tags transmit a signal to the master unit and the master unit measures the RSSI value from that.

For the antenna, we decided to use a PCB antenna as this was more compact and inexpensive. The design of the antenna was motivated by the documents provided by the microcontroller manufacturer, Texas Instruments. They explain in detail the possible antenna choices and the design constraints associated with them. The documents detailing this can be found in the references. In addition to the antenna design, the necessary impedance matching was also applied via the recommended component by the manufacturer. An impedance-matched balun filter was used to solve this issue. Again, the related documentation is included in the references for further elaboration on the topic.

The antenna does not have a uniform pattern in terms of the RSSI values with respect to the angle between the master unit and the tags. This was an intended design decision made by us. Since the animal would be more likely to move in the direction they are pointed at, giving the same level of alert for the same distance in the cases where the animal was pointed towards the tag and was looking at somewhere else would not result in a desirable case. One may think of this design decision as a way to somewhat assess the possible trajectory of the animal on the hardware side.

3.2.2. Control Subsystem

For the control subsystem, the CC2640R2 microprocessor was chosen. This microprocessor is a part of TI's "SimpleLink" series, which was designed for over-the-air communication implementations through 2.44 GHz RF waves, which is perfect for our case. This microprocessor was selected because this has the lowest cost out of the series and gives us the performance we desire, nonetheless. Furthermore, TI provides its users with an open-source framework to make project development easier, which some team members are familiar with.

CC2640R2 is sold in different variants. The one we chose was CC2640R2L. This one has the lowest amount of pins, and also the lowest specs (such as in terms of flash memory, RAM etc.). However, it is the best in terms of cost. Since the features provided by the higher variants were considered unnecessary, this one was chosen.

As for TI's ready-to-use framework, TI-RTOS (TI real-time operating system), it provides great convenience and saves us a lot of time. However, the framework is written in C (while we prefer C++ in order to be able to use an object-oriented approach) and is quite lacking in terms of readability. As such, the given framework was abstracted under our framework, which was written in C++ with an object-oriented programming approach. This way, TI's code is hidden, and the general structure of the code has much better readability, which we believe is vital for the whole team to be able to understand the code and contribute to it.

The firmware abstracts the peripherals as objects, such as the RF capabilities (the connection between this submodule and the detection submodule) and the UART port (which proved vital for testing). The "application" is the main part of the code, which is the part where the main functions of the firmware are set up. Of course, the project contains a "master unit" and "tags", so the firmware for these are separate (the tags have the same firmware between themselves). They share the same framework structure, however.

The control subsystem works like this: the tags continuously transmit RF packages. The master receives these packages. The RSSI value is calculated and then stored in association with the specific tag.

In order to determine the distance using RSSI, the following formula is used:

$$distance = 100 * 10^{(RSSI_{ref} - RSSI_{meas})/(10n)}$$

where; $RSSI_{ref}$ is the empirically found RSSI value for 1 meter,

$RSSI_{meas}$ is the measured RSSI value,

n is the propagation exponent representing the environment found empirically.

This formula models the relationship between distance and RSSI as a logarithmic function. The distance acquired from this formula cannot be used directly, however. The noise that RSSI measurements carry is far from being negligible, and as such, the found values must be filtered first.

There are many factors to be considered for a filter. For a more robust implementation, a strong filter is required. However, a strong filter will reduce reaction speed, as many samples will need to be required for the system to drift from one state to another. This problem was solved by increasing the sampling rate. The sampling rate is limited by the hardware capabilities of the system; thus, this parameter was optimized to obtain the best scenario.

Keeping this in mind, different filters were experimented with. The most constraining factors ended up being robustness and reaction speed. We realized that with the hardware at hand, we needed to compromise from either. We ended "giving and taking", compromising from both to what we perceived as acceptable levels.

In our type of application, Kalman filters are widely used. A Kalman filter is a type of filter that uses the previous state of the system together with the current measurement to predict the next state of the system. The "uncertainty" of the system determines how much one should "trust" the current measurement. If the uncertainty is low, then the measurement can be trusted to be correct. If it is not, then the measurement should be taken with a grain of salt, that is the previous state of the system should be more important when determining the next state. This "uncertainty" may be modeled in many ways, which we chose to model with variance.

One problem with Kalman filters, however, is that they are not time-critical. However, since pets can act suddenly, we do not have time to wait. We cannot wait for a number of samples to be received before we can filter our data, filtering must be done with every sample received. We used the following formulae to achieve this:

$$distance_{filtered} = distance_{prev} * (1 - k) + distance_{raw} * k$$

$$where;\ k = 1/(1 + variance),$$

$distance_{filtered}$ is the computed distance value,

$distance_{prev}$ is the distance value that was computed in the previous cycle,

$distance_{raw}$ is the unfiltered distance value found by the prior formula.

Once the "filtered" distance is found, we now have an estimation for the distance between the master and the tag. This estimation can now be passed on to the alerting subsystem.

3.2.3. Alerting Subsystem

The alerting subsystem is tasked with alerting the pet, as its name implies, when it enters the forbidden zones. The alerting system is the simplest subsystem of the system, it receives feedback from the control subsystem about how close the pet is to the tag, and alerts the pet appropriately.

The alerting subsystem works with a buzzer, that is through sound and to a lesser degree vibration. The buzzer goes off whenever the pet enters the forbidden area, and increases its frequency with increasing levels of proximity, aimed at making the sound more and more disturbing for the pet. Four different levels of proximity are defined, these are;

- <u>Out of range:</u> the pet is outside the range of the tag. No alerting is done.
- <u>Near:</u> the pet has entered the range of the tag. The lowest level of alert is given.

- Close: there is little distance between the pet and the tag. The alerting magnitude is increased.
- Too close: there is close to no distance left between the pet and the tag. The alerting magnitude reaches its maximum level.

The reason our states are discrete is because of the nature of our system, we cannot confidently claim that our distance estimations have low enough error margins for a continuous distribution to be feasible. Since our error margins depend on the environment, we believe that this implementation will make the device feel more robust. It is expected that the transition distances do not change for the same environment.

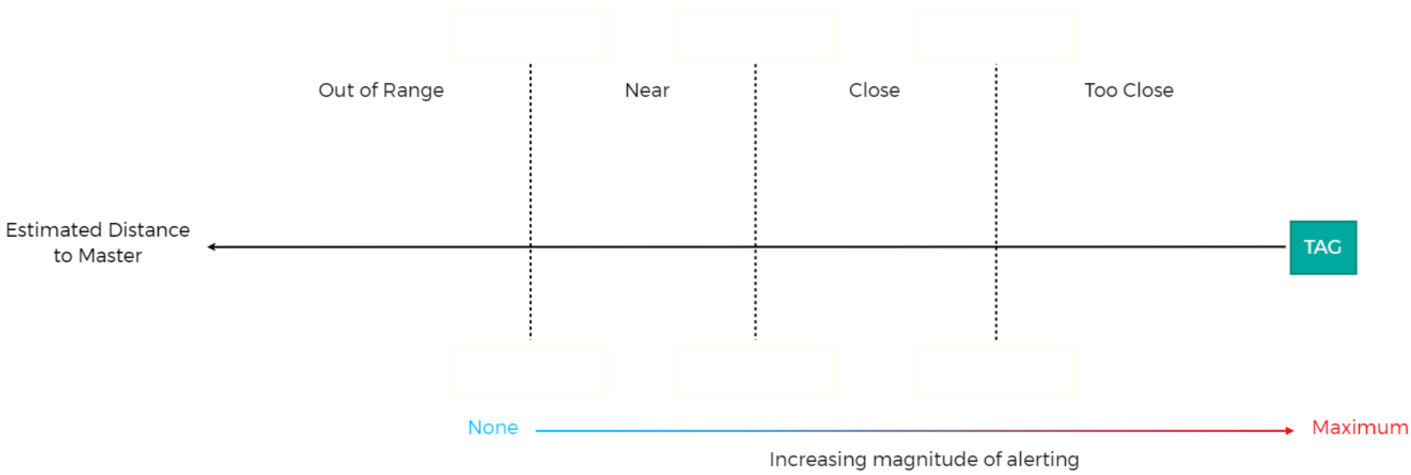


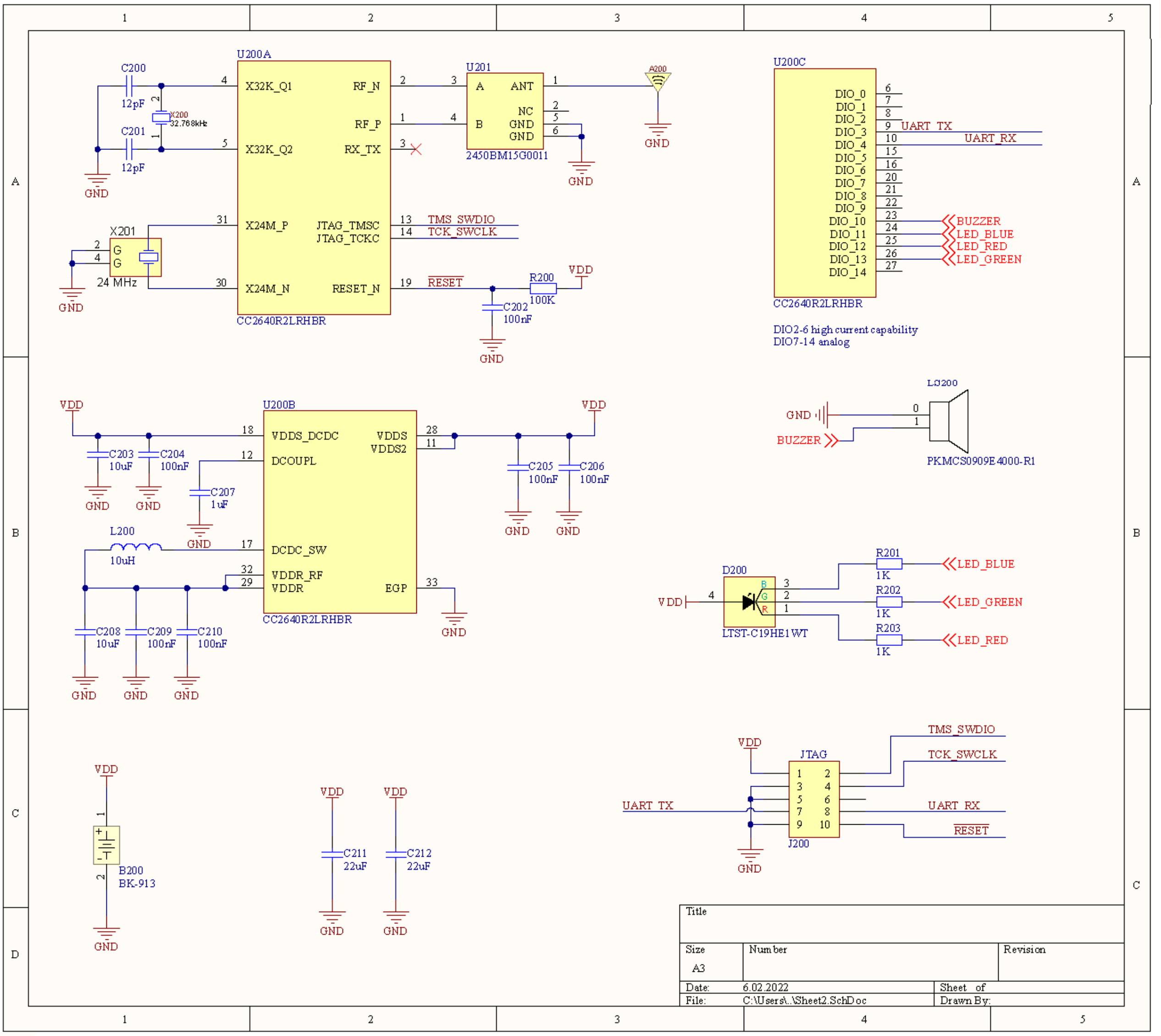
Figure 3.8 *Visualization of four different levels of proximity*

3.3. PCB Design

While designing the PCB, the guidelines provided by TI (manufacturer of the used microcontroller) were followed. This document details the steps that the developer must take while designing the PCB.

On the PCB, we have the microcontroller, CC2640R2LRHBR. Only one of its pins is used, and that is for the buzzer. The schematic also has an RGB LED, as well as shows the pins that it is connected to, however, these are unused in the final design. The other ports of the microcontroller were configured adhering strictly to the guidelines. The microcontroller is also connected to the antenna, through the balun.

Figure 3.9 *Schematic of the designed circuit for the PCB design*



A balun was used for impedance matching, as told by TI. The balun chosen was Johanson's 2450BM15G0011, which is the model TI recommends. The antenna itself is a PCB antenna. Its cookbook is likewise provided by TI. The reason for using a PCB antenna is the lower cost. Finally, there is the retainer for the CR2032 battery. For the manufacturing of the PCB, JLPCB was preferred, once again thanks to its lower costs.

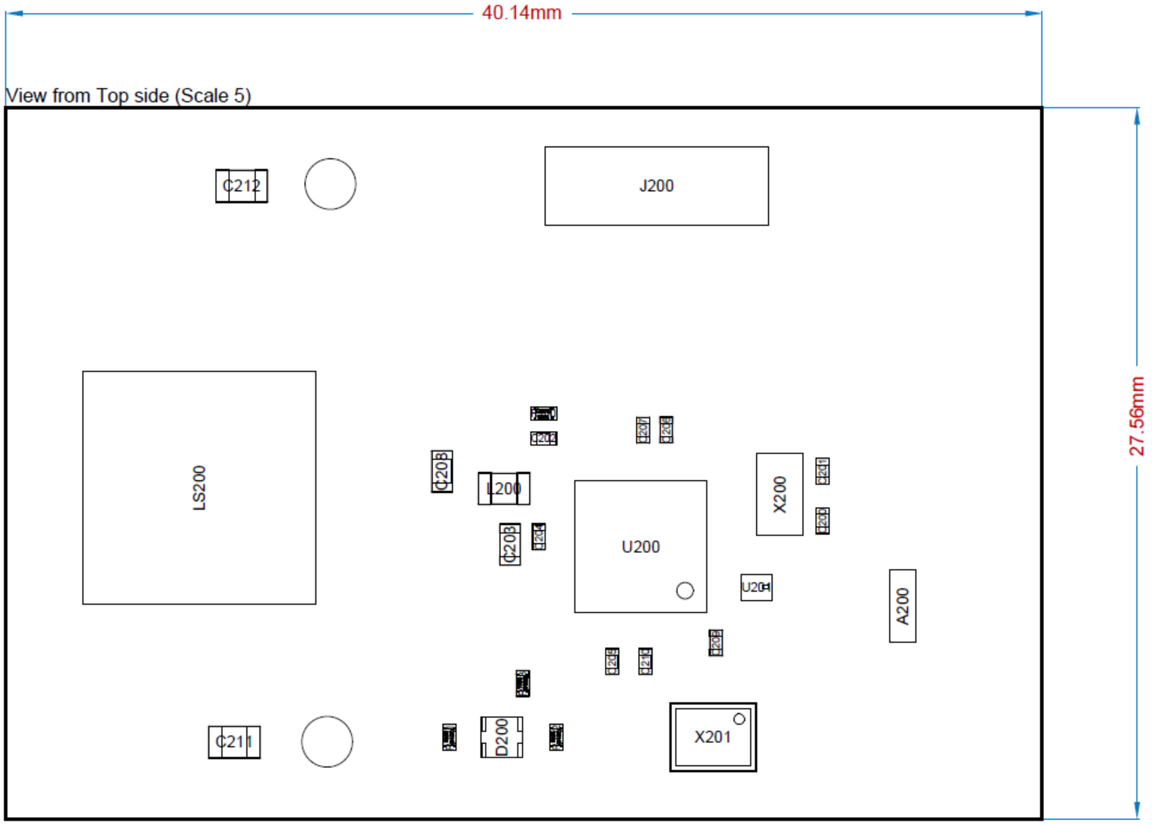


Figure 3.10 *Component layout on the PCB*

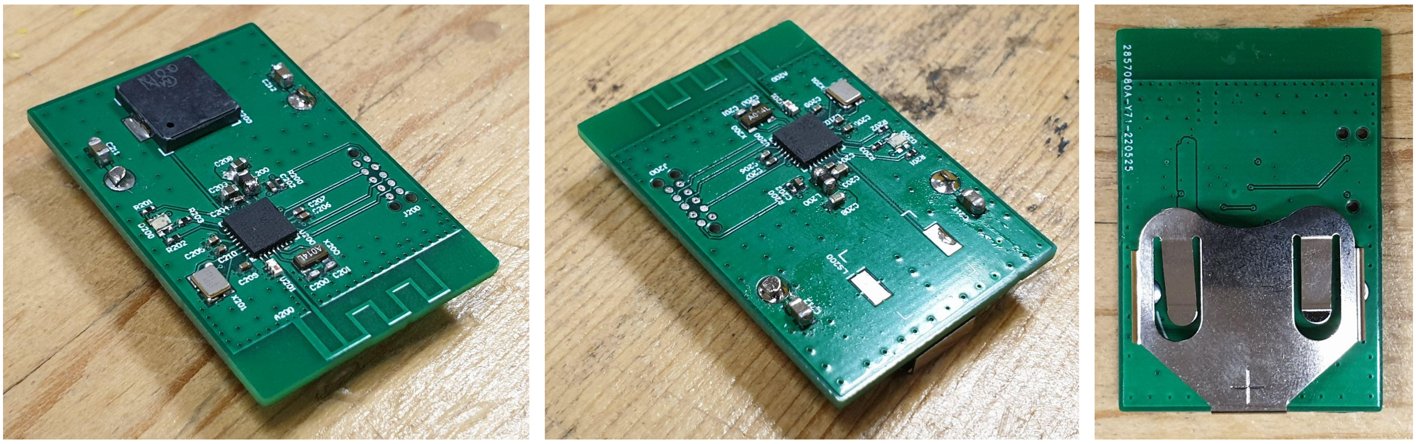


Figure 3.11 *PCBs used for the project with and without buzzer with their backside*

3.4. Final Product & Operation Details

The figure below shows the orientation of the master and a tag that gives the most stable RSSI readings. Note that this is not the only orientation our system works at, which is further elaborated in the testing part of the report. This orientation case was used as the control case for operational tests.

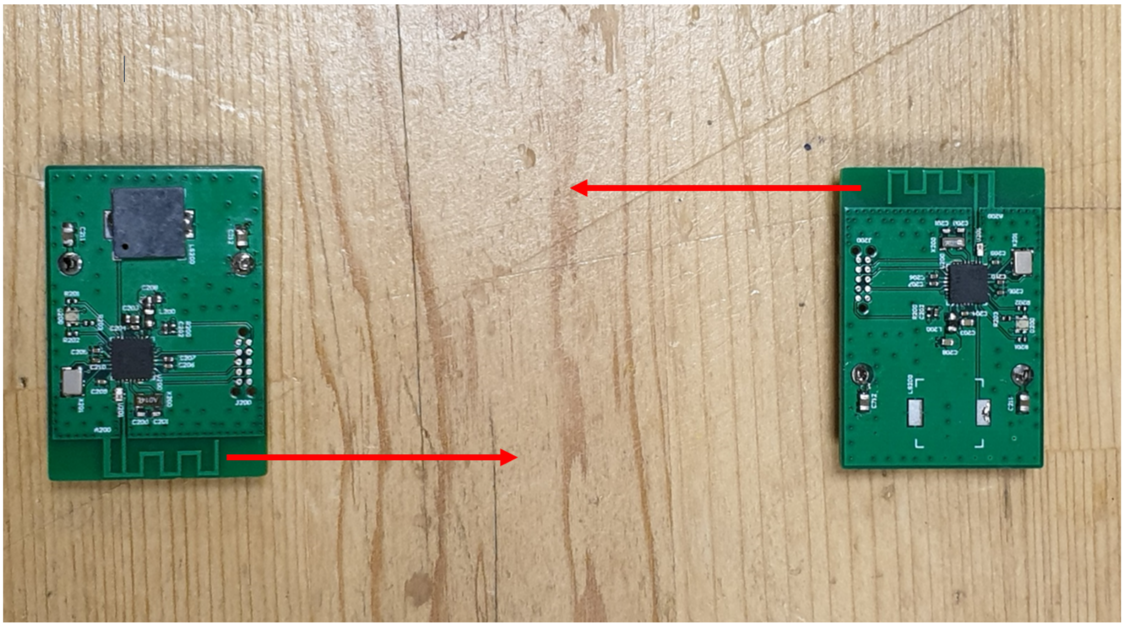


Figure 3.12 *Control Case Positioning of Master Unit & a Tag (showing the signal directions)*

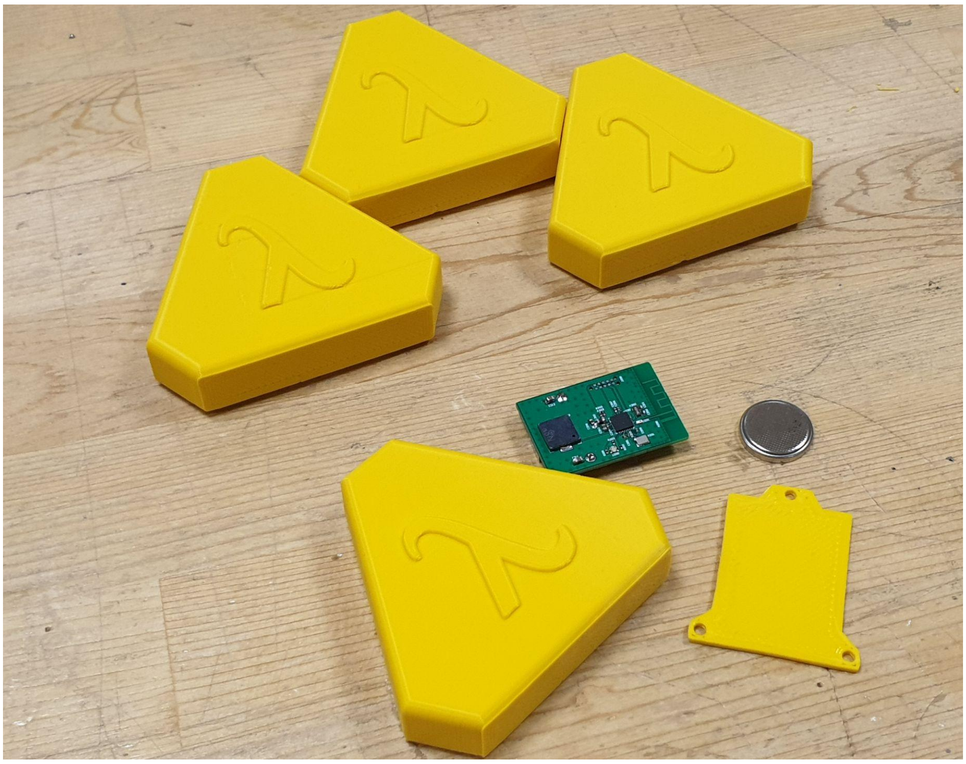


Figure 3.14 *Master Unit Components & Tags*

4. Results and Analyses of Performance Tests

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

4.1. Test Procedures

The test procedures were structured to give insights into the day-to-day operation of the system, as well as its technical specifications. Some of the experiments focus on obtaining specific values from the setup such as the distances at which state changes happen. Other experiments are used to determine the practicality of the system. For example, the distance between the master unit and a tag is changed rapidly to observe if any of the possible states were missed. Each case is presented in the experiments part and the associated result can be found in the table. An elaboration on the results are given afterwards.

4.2. Experiments

Distance Estimation Testing Scenarios						
	Test Case	Tag-Master Height Difference	Tag-Master Facing Direction	Measurements		
				Far State Entry Distance (cm)	Medium State Entry Distance (cm)	Close State Entry Distance (cm)
Zone Tag	Walking towards & away	0 cm (At the same height)	[1]Facing towards	76	40	16
	Walking towards & away	0 cm (At the same height)	[2]Facing 45°	54	33	14
	Walking towards & away	0 cm (At the same height)	[3]Facing 90°	67	45	19
	Walking towards & away	[4]Tag is 40 cm higher than master	[1]Facing towards	60	45	-

[1]*Facing towards:* *Antennas pointing towards each other.*

[2]*Facing 45°:* *The master unit is rotated 45 degrees on the plane parallel to the ground surface.*

[3]*Facing 90°:* *The master unit is rotated 90 degrees on the plane parallel to the ground surface.*

[4]*Tag is 40 cm higher than the master:* *The direct path is used for the measurements.*

Miscellaneous Testing Scenarios										
	Test Case	**Tag - Master Height Difference**	**Tag - Master Facing Direction**	**Reaction Speed**		**How many states were skipped?**		**Were the appropriate states entered within the expected time?**		
				Measurement	**Max. Reaction Time**	**Measurement**	**Max. Skipped State**	**Measurement**	**Max. Reaction Time**	
Tag Classification	During start-up/operation, the tags will be classified as either zone or door tags	0 cm (At the same height)	[1]Facing towards	~2s	2s	N/A	N/A	N/A	N/A	
Zone Tag	Approaching in a straight trajectory, slowly	0 cm (At the same height)	[1]Facing towards	N/A	N/A	0	0	<1s	2s	
	Approaching in a straight trajectory, fast	0 cm (At the same height)	[1]Facing towards	N/A	N/A	1	0	<1s	2s	
	Approaching in spiral trajectory	0 cm (At the same height)	Alternating direction	N/A	N/A	1	1	~1s	2s	

For elaboration on the test results, the state entry distances found by experimentation were aligned with our practical application standards. We would like to note that the importance of the inner state entry points are more critical for alerting the pet than the outer entry states as the highest level of warning is designed to be the main deterrent. In the design of the system, a tradeoff was present for the reaction speed and the robustness, mainly for the far state entry. As we do not want the device to give alarms in a non-robust way, we decided to decrease our far state entry distance predictability for different angled approach paths to increase the robustness of the system. Note that this does not decrease the practicality of the product as the warning state is still present, only with some more angle dependence.

For the reaction speed and state tests, the results are deemed as acceptable by us since the measurements were close to our success metrics. The door tag classification was quick enough to be practically applicable. In addition to this, the system did skip only a few states, within or close to our success metrics.

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5. Budget

5.1. Actual Expenditures

Type of Expenses	Items	Number of Pieces	Unit Cost(*)	Total Cost
Final Product Costs	PCB (for manufacturing)	4	0.8 $	3.2 $
	"CC2640 Microcontroller - Texas Instruments"	4	1.78 $	7.12 $
	Buzzer	1	0.53 $	0.53 $
	Balun	4	0.23 $	0.92 $
	Other Passive Components	-	-	2 $
	Power Supply "Button Battery – 3.3V"	4	0.5 $	2 $
	Mass Production Enclosures	4	0.5 $	2 $
Total Final Product Costs				**17.77 $**

Figure 5.1 *Cost analysis table for the product*

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

5.2. Total Cost

<table>
<tr><th>Type of Expenses</th><th>Items</th><th>Number of Pieces</th><th>Unit Cost(*)</th><th>Total Cost</th></tr>
<tr><td rowspan="7">Final Product Costs</td><td>PCB (for manufacturing)</td><td>4</td><td>0.8 $</td><td>3.2 $</td></tr>
<tr><td>"CC2640 Microcontroller - Texas Instruments"</td><td>4</td><td>1.78 $</td><td>7.12 $</td></tr>
<tr><td>Buzzer</td><td>1</td><td>0.53 $</td><td>0.53 $</td></tr>
<tr><td>Balun</td><td>4</td><td>0.23 $</td><td>0.92 $</td></tr>
<tr><td>Other Passive Components</td><td>-</td><td>-</td><td>2 $</td></tr>
<tr><td>Power Supply "Button Battery – 3.3V"</td><td>4</td><td>0.5 $</td><td>2 $</td></tr>
<tr><td>Mass Production Enclosures</td><td>4</td><td>0.5 $</td><td>2 $</td></tr>
<tr><td colspan="4">Total Final Product Costs</td><td>17.77 $</td></tr>
<tr><td rowspan="5">R&D Costs</td><td>Sticking Device (for Tags)</td><td>10</td><td>0.072 $</td><td>0.72 $</td></tr>
<tr><td>Wearables for Animals "Simple Collar"</td><td>1</td><td>2.82 $</td><td>2.82 $</td></tr>
<tr><td>LAUNCHXL-CC2640R2</td><td>3</td><td>40 $</td><td>120 $</td></tr>
<tr><td>Enclosure for PCBs</td><td>4</td><td>1.5 $</td><td>6 $</td></tr>
<tr><td>Enclosure for LaunchPads</td><td>4</td><td>1.5 $</td><td>6 $</td></tr>
<tr><td colspan="4">Total R&D Costs</td><td>135.54 $</td></tr>
<tr><td colspan="4">TOTAL COST</td><td>153.31 $</td></tr>
</table>

Figure 5.1 *Cost analysis table for the combination of the product and R&D*

The total price of the final product is nearly 18$ which makes the company highly advantageous against the other possible competitors in the market. This is well below the budget assigned to us and this was one of the criteria we were trying to achieve. Because the price is affordable, the accessibility of the device is much higher. This yields a more impactful and practical system that can be used with competitive pricing.

6. Power Analysis

There are three components/systems in the project that will consume power. These are,

- RF Communication Module in the CC2640 microcontroller
- The microprocessor in the microcontroller itself
- The Buzzer in the master unit

Using a multimeter and a power supply, the current was measured as 10mA. The team tested both the master unit and the tags under different conditions such as changing the number of active tags and the distance. Interestingly, in all these cases the current draw was the same at 10mA. Considering that the supply voltage was 3V, we have a power consumption of 30mW in all cases. This was not the case for the prototypes used in the previous tests (the CC2640R2 Launchpad). In those cases, the power was much different for the master unit. However, the power consumption of the buzzer seems to be negligible when we compare it to the total power consumption of the system. Long story short, we have a power consumption of 30mW in all possible tested cases.

Note that only the total power consumption of the product was calculated, not its subsystems. This was the case as it is difficult and, in our opinion, not practical for one to try to measure the consumption of subsystems one-by-one. As the total power consumption is the main criterion, this is sufficient to calculate.

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7. Deliverables

Lambda company always tries to be customer-oriented with the projects and works it produces. It produces environmentally friendly materials and systems with its work. With the project, it aims to be animal-friendly as well as user-friendly. At this stage, it promises the product warranty and longevity to the user. Within the scope of the project, some of the elements that we have created with a customer-oriented and conveyed to the customer with the product are listed below:

The Content of Product

I. Master Unit for Pets

A structure is 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 for Forbidden Areas and Doorways

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.

III. Device Batteries

The system needs 3V CR2032 Lithium batteries to operate. For the user to use the system in the most effective and long-lasting way, Lambda shares the first batteries with the user to be used with the system in the first stage. One battery is offered to the user for each zone tag and the main unit that comes out of the system.

IV. 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. Lambda reserves all personal data on this subject. Lambda company reserves the right to share it with third parties or not.

V. User Manual

The user manual is given in the Appendix Section.

Service and Technical Hardware Support

- ➔ Within the scope of service and repair services, the defective product covered by the warranty is shipped to the nearest authorized service. After the repair service for temporary problems, the working, ready system is delivered to the customer as soon as possible.
- ➔ For non-repairable systems, unused, new products are sent to the customer.

8. Discussions

Safety Issues Associated with Design and Precautions

- **Electrical Safety:**

The system is designed to operate with a 3V battery. There are no elements in the circuit, such as amplifiers or current relays, that will harm the animal in any way. However, Lambda Company has used a durable and stable coating covered with plastic material to prevent splintering and wetting in case of any mishap. These plastic parts in the circuits are 90% reliable against electrical safety issues.

- **The Explosion of Power Supplies:**

The 3V button battery used in the system is more reliable and stable than other brand pen batteries. The probability of explosion in case of heating, getting wet, being under pressure, and being deformed is very low compared to other batteries. Apart from this, their chemical damage to the environment is also lower.

- **Ingestion by Pets:**

Lambda company has taken care to keep the PCB and circuit elements used in the design phase to a minimum in terms of efficiency and cost. However, since the reduction in size increases the possibility of the device being swallowed by animals, the outer part that protects the circuit elements has been designed by enlarging it in appropriate dimensions. Thus, any swallowing event is made more difficult.

Although Lambda uses durable and stable parts, the problems caused by small parts that may occur in case of any biting, biting, and shredding are the responsibility of the user as it is not possible to completely eliminate these factors.

- **Radiation Limits:**

The antenna used in the system uses electromagnetic signals to make RSSI measurements. During transmission, these waves emit certain radiation to the environment. This radiation level is called the Specific Absorption Rate. IEEE has determined SAR levels, and the printed antenna we designed works within these levels. Since the SAR level is directly proportional to the power supplied to the antenna, this level is not at a very important level within the scope of the “CISS” project. Thus, there is no radiation affecting people and pets outside the borders in the home environment.

As the operating frequency of the antenna is 2.4 GHz, which is the same as WiFi and Bluetooth, it is a well-researched topic and IEEE approves the usage of such frequencies.

A Possible Widespread Application of Product

- ➔ In-Door or Out-Door Target Position Management

The system can be used for other applications where the master may not be connected to a pet. The same master-tag configurations will result in similar outputs for other objects as well.

- ➔ Anti-burglary Systems

The master can be attached to valuable items and the tags can be positioned at exit points to have a system similar to alarm systems that are commonly used.

Potential Environmental Effects

Within the scope of product content and operating principle, Lambda ensures minimum negative environmental impact. All interactions with the frequency range that the system operates, the radiation it emits during broadcasting, the amount of energy it uses, and its materials are within certain and appropriate universal limitations. After using the product, the materials should be thrown into appropriate recycling bins, and waste batteries should be disposed of under appropriate conditions. Potential environmental pollution may occur if wastes or batteries are released into nature.

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9. Conclusion

The solution that was created for the given problem was discussed in detail. This approach uses RF waves to communicate between two devices (master and tag). Using the **RSSI measurement**, the master calculates an estimate of the distance between itself and the tag. The estimate is then used to alert the wearer of their proximity level after tiers of processing. The test cases and results show that the practicality of the system is well within our standards. The master unit and the tags were optimized in terms of their size, functionality and cost.

Using RSSI for distance measurement for relatively short distances, which is the case we have, turned out to be a challenge. However, we believe that the possible distance measurement inaccuracies were reasonable in terms of the practical usage case. In addition to this, implementing other solutions for the distance measurement would be more costly and increase the size of our master unit and the tags. The design decisions made throughout the process were justified by the fact that the device should be small and low-cost. The potential accuracy improvements that could have been achieved by other implementations would not have met our criteria for unneeded accuracy improvements. As a result, we think that we created a well-thought solution for the problem.

As a result, we believe that our product is more than a project that was done for the sake of doing it. The device can be used in practical applications by various users that have pets in their homes.

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10. References

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[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

[4]TI RF PCB Cookbook - https://www.ti.com/lit/pdf/swra638

[5]CC2640R2L Datasheet - https://www.ti.com/lit/gpn/cc2640r2l

[6]CC2640R2L Technical Reference - https://www.ti.com/lit/pdf/swcu117

[7]TI PCB Antenna Manual - https://www.ti.com/lit/pdf/swra726

[8]TI Balun Recommendation - https://www.ti.com/lit/pdf/swra572

11. Appendix

11.1. User Manual

11.1.1. Usage

- Read the ENTIRE instruction manual to become familiar with the features of the product before operating.
- The recommended battery voltage is 3V. The maximum allowed voltage is ~ 5V. Never use non-approved batteries or the ones having more than a 5V supply. Failure to comply may result in excessive heat, fire, and serious injury.
- ALWAYS connect the positive red leads (+) and negative black leads (-) of the battery correctly.
- Do NOT allow pets to touch devices. Be sure that the enclosure is closed completely.
- Do NOT attempt to use dead, damaged, or wet devices, enclosures and batteries.
- TURN OFF the device as soon as possible if any malfunction occurs, indications of which may be smelling, overheating or visible damage.

11.1.2. Exterior

- Both the master unit and tags have the same components shown below.

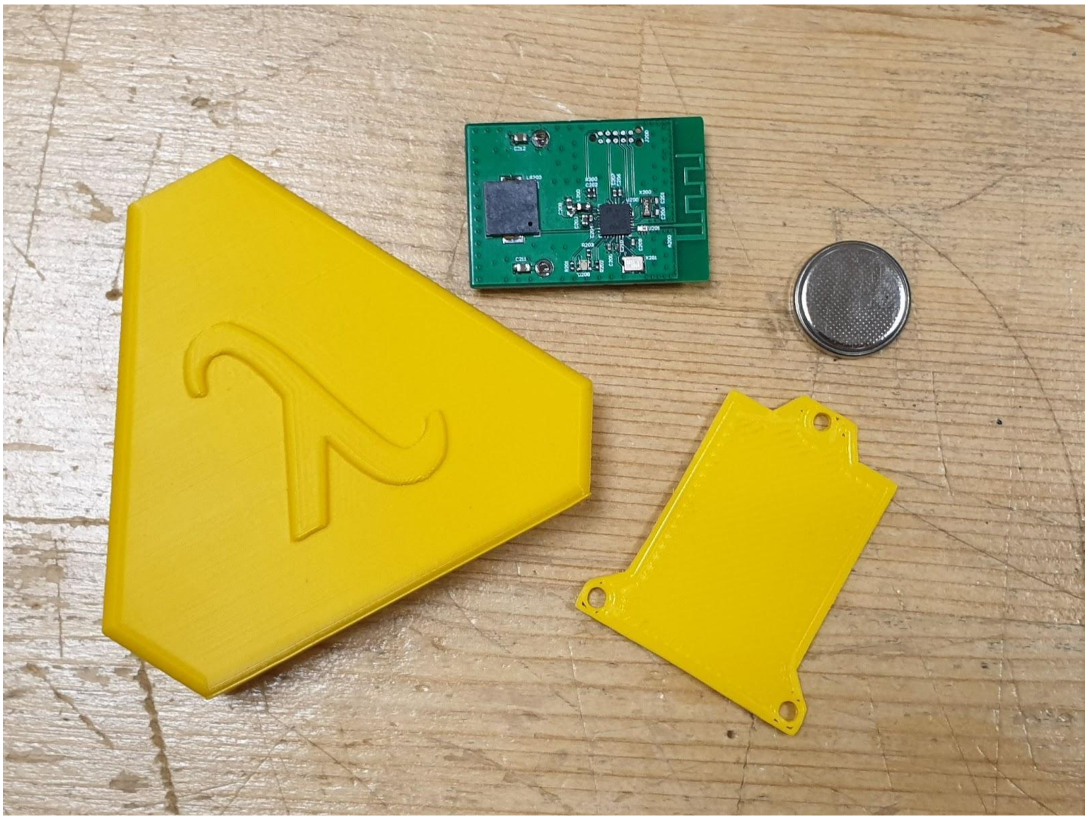

Figure 11.1 *Components of each one of Master Unit & Tags*

11.1.3. Storage

- Do NOT expose the master unit and tags directly to dust, damp, water, rain, heat, sunshine, and vibration. Do NOT let any physical damage occur to them such as dropping.

11.1.4. Environment Requirements

- Ambient Temperature: -40℃ – 85℃ (Theoretically)
- Ambient Humidity: 5% – 95% (Theoretically)
- Storage Temp.: -40℃ – 150℃ (Theoretically)
- Storage Humidity: 30% – 90% (Theoretically)

11.1.5. Mechanical Characteristics

- Size: 77:67:17 (L:W:H, mm) (for each unit with its enclosure)
- Weight: ~75g (for each unit with its enclosure)

11.1.6. Connection

Apply the following steps carefully for the first setup explained in the figure.

- Plug the battery into the back of the device(1) as shown in the figure.
- Put the device into its enclosure(2) as shown such that the antenna is heading to the top edge.
- Close the enclosure with its cover(3).

Follow the same instructions while changing the battery.

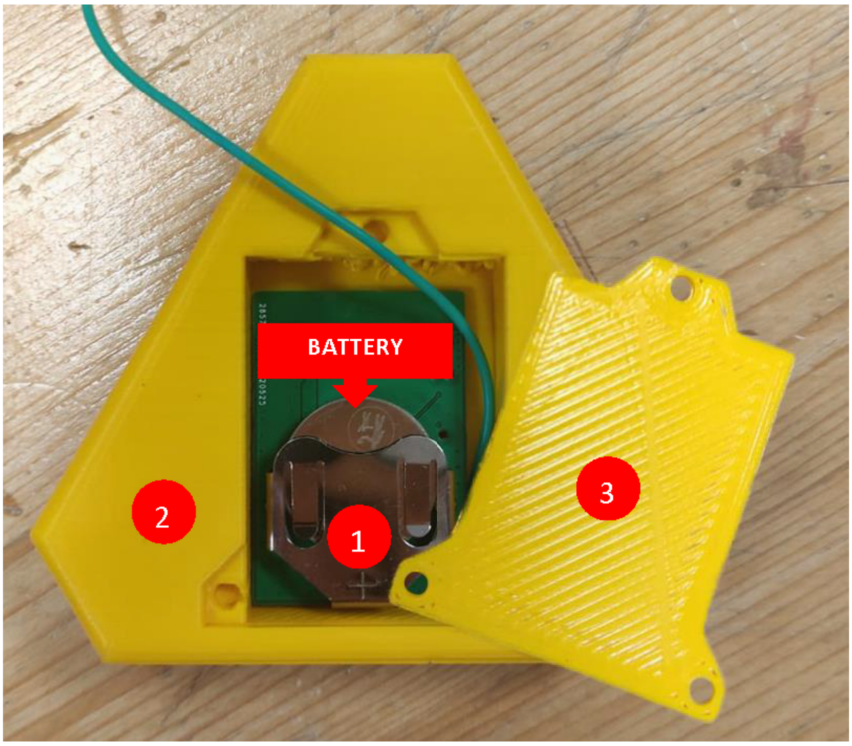

Figure 11.2 *Picture showing the instructions for the first setup and battery change*