Design Document for a Solution to Lost WatCards

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Content

1. Needs Assessment

1.1 Customer Definition

Our customers will be the 42,000 part-time and full-time students [1] currently enrolled at the University of Waterloo. A full-time student is defined as someone either on a co-op term or taking at least 1.5 academic credits worth of courses in a term. A part-time student is defined as someone who is taking less than 1.5 academic credits worth of courses in a term [2]. A watcard is the form of identification given to both part-time and full-time students [3]. Studies show that when a person is anxious and stressed they are more likely to lose important items [4]. Not only that, when a person loses an item, it causes them further stress building onto their already poor mental health [5] and making what was already a bad day for them turned even worse. On top of that, a $30 replacement cost [6] while on a tight budget will only further the emotional distress of an individual [7]. By using our product, our customers, the Waterloo student body, who already possess higher stress levels than the average individual [8] will be able to easily locate their WatCards, removing a huge source of stress from their hectic lives. In addition, the 2.5 days saved [9] in looking for lost items helps not only improve the students mental health, but also reinstates their precious time.

1.2 Problem Statement

WatCards are a crucial aspect of student life at the University of Waterloo. Not only are they a basic form of identification used, the card also provides students with other services, such as: access to student residences, transportation across the Waterloo Region Grand River Transit, ability to purchase foods at on campus food service locations, and entrance to the student-offered Physical Activities Complex (PAC) [3]. However, regardless of its importance, it is estimated that between 0.001% to 0.005% (42 to 210) WatCards are lost per month, with busier seasons, mainly the fall term and exam periods, boasting higher loss percentages [10].

1.3 Competitive Landscape

1. The Apple AirTag is a lightweight tracking device designed to help you locate misplaced or stolen items. The AirTag uses Ultra Wideband technology to offer precise location tracking with directional guidance [11]. The downside of this however is their limited compatibility. AirTags are designed to work exclusively with Apple devices, if you have an Android device, you will be unable to take full advantage of the features. Furthermore, there have been privacy concerns as unwanted tracking can easily be hidden without one's knowledge [12].
2. Samsung Galaxy Smart Tag is a Bluetooth tracking device that assists users in locating their belongings. It has a SmartThings Find feature which allows its user to see the last known location of their SmartTag on a map [13], even playing a sound if nearby. However, some drawbacks include its compatibility. The SmartTag is designed to work seamlessly with Samsung Galaxy devices, but this means that for other Android and iPhone users, it becomes unusable [14].
3. The Jiobit is a small and long-lasting GPS tracker designed to help parents keep track of their kids. It provides real-time location updates [15] and comes with long battery life. Some shortcomings of the Jiobit include the $129.99 upfront cost of the device and the need for a monthly subscription plan, which costs $14.99 per month [16].

1.4 Requirement Specifications

- As the person holding the locator device gets closer to the WatCard holder, the LED will start blinking once it reaches a distance threshold of **5m** [17].
- The blinking speed of the LED increases inversely proportional to the distance **(1/distance)Hz** between the WatCard holder and the locator device, but the blinking will **not surpass 100 Hz** as to reduce eye strain [18].
- Locator device has a button that triggers a speaker on the WatCard holder, playing a chime at **70-85dB** to help you locate it, but not any higher to lower the risk of ear damage [19].

- Locator device is able to find the WatCard within **10m**, as that is the limitation of Bluetooth technology [20].
- A navigation **update rate of 5Hz** [21] to ensure that the device is sending up-to-date information on its location without expending too much power.

2. Analysis

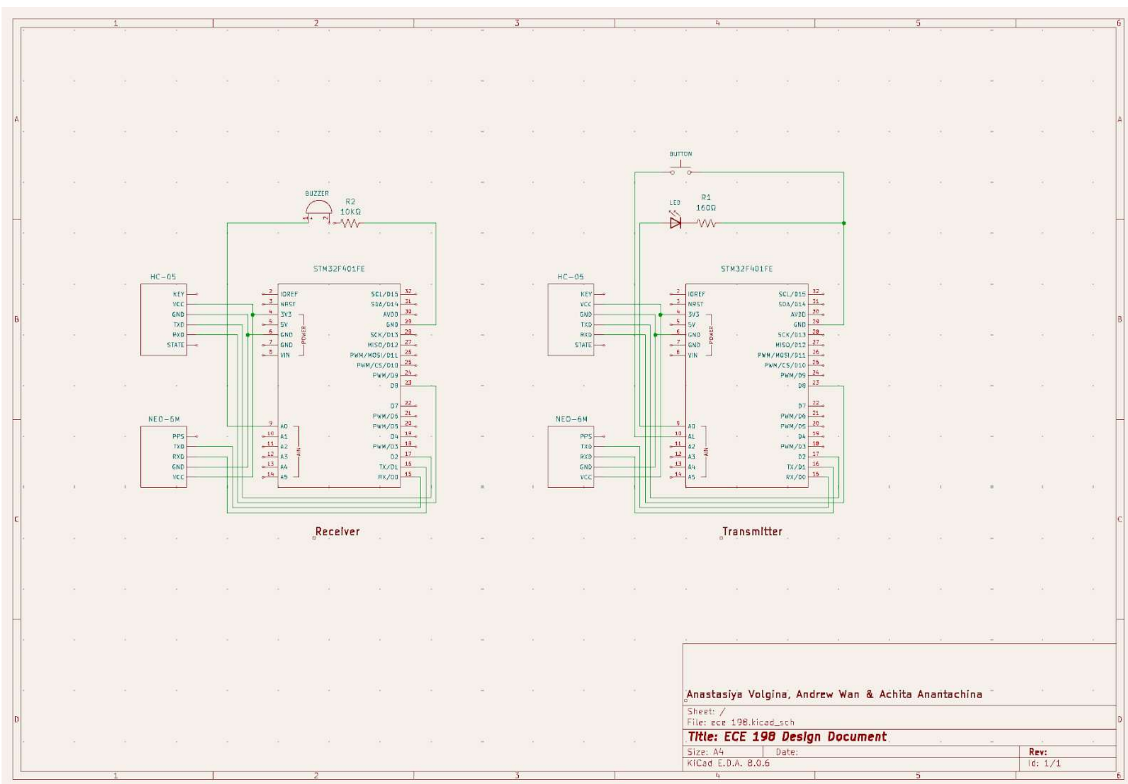
2.1 Design

2.1.1 Assembly Process

Both Nucleo STM32F40REs will each be fitted with a UC-05 (bluetooth module) and NEO-6M (GPS module) which should ensure that the device has a working range of 10m (Requirement 4) [22]. The data will be transmitted between the two Nucleo STM32F40RE controllers via USART1 RX [23] via the UC-05 modules. The data will be transmitted at a rate of 5Hz (Requirement 5) and will contain the location data provided by the NEO-6M module. The receiver Nucleo STM32F40RE will then compare the results it received with its current location to determine how far the other Nucleo STM32F40RE is from it.

To assemble the transmitter module, the user must first install the Bluetooth Module onto the Nucleo STM32F40RE. First, connect the VCC pin of the Bluetooth module to the 3.3V output pin on the Nucleo STM32F40RE Nucleo board. Next, connect the GND to GND and connect the GND pin of the Bluetooth module to one of the GND pins on the Nucleo board. For the Data Connections, connect the Bluetooth TXD to Nucleo STM32F40RE RXD, connecting the TXD pin of the Bluetooth module to PA10 on the Nucleo STM32F40RE (USART1 RX). Next, connect the Bluetooth RXD to Nucleo STM32F40RE TXD and connect the RXD pin of the Bluetooth module to PA9 on the Nucleo STM32F40RE (USART1 TX). Finally, add the pin to 3.3V through a resistor. Then on pin A1, set it to a pullup resistor and connect the button with wires. An LED will then be connected to A0 with a 160Ω resistor.

For the receiver module, connect the power VCC to 3.3V or an external supply. Next, connect the VCC pin of the GPS module to the 3.3V output on the Nucleo STM32F40RE or an external 3.3V supply if more current is needed. Next, connect the GND to GND and connect the GND pin of the GPS module to one of the GND pins on the Nucleo board. Additionally, we need to add data connections, GPS TXD to Nucleo STM32F40RE RXD by connecting the TXD pin of the GPS module to PA3 on the Nucleo STM32F40RE (USART2 RX). Finally attach the buzzer with a 10KΩ resistor to pin A0.



[**Fig.1** Schematic of wiring]

This process will run in an infinite loop, 5 times per second, constantly asking the other Nucleo STM32F40RE for its location. It will then use the L-2 Norm algorithm [24] to figure out the distance between the two Nucleo STM32F40REs. Once the distance is within 10m, it will start to play a chime between 70-85dB (Requirement 3). When it is within 5m it will turn on an LED (Requirement 1) and for every step closer you get to it, it will blink inversely proportional at a rate of (1/distance)Hz, signifying that it is getting closer to the other microcontroller (Requirement 2).

The design will be user friendly and will always be active, but has an option to prevent the LED and sound from playing.

2.1.2 Alternatives

Multiple LEDs:

Initially instead of blinking one LED faster and faster as we approached the WatCard, we had the idea of having multiple LEDs and turning on more and more LEDs as we got closer and closer to the WatCard. In the end we rejected this idea as this would lead to more light and environmental pollution along with consuming more power [25]. More LEDs would first use more materials as each LED takes plastics, metals and packaging materials for us to receive more LEDs [26]. In addition more LEDs would also lead to more light pollution and even though that is a small concern, it is still a concern especially in more rural areas or at night. Finally we decided not to go with this because it consumes more electricity, along with more part fatigue [27]. Due to these reasons we decided to change our design to a blinking LED.

Wifi instead of Bluetooth:

Initially we wanted to use Wifi instead of bluetooth as it would increase the range our Nucleo STM32F40REs could communicate to each other from 10m to up to 100 m [28]. We decided against this due to the costs and power consumption required to sustain a wifi network. From our calculations, setting up a wifi network [29] would take 4x the costs compared to a bluetooth network from all the extra parts we would need to purchase. In addition, it takes at least 300mA to power a wifi module [30] while only 30mA for a bluetooth module such as the HC-05 we are currently using [31]. This is over 10x the difference in power consumption, and in addition to the extra costs, we decided that this is not the best solution for our device.

2.2 Principles

1. **GPS - Vector Coord System (NSEW)**: To understand the GPS output, we must first understand the math behind it. In the context of the GPS, the coordinate system used is based on a two-dimensional Cartesian framework, often represented in terms of the North-South-East-West (NSEW) orientation [32]. A location is expressed as a vector:

$$\vec{s} = \ < x,\ y > \quad \ldots\ (eq.\ 1)$$

   Here, x indicates the East-West displacement, while y denotes the North-South displacement. This vector is an element of the Euclidean space $\mathbb{R}^2$, with the components relative to a defined origin. The NEO-6M is the device that allows us to receive a GPS vector coordinate system, returning an output in the format seen below:

```
$GPGGA,072842.00,3015.8564,N,07802.0406,E,1,04,3.8,591.2
```

   The data can then be parsed in such a way that we can obtain the global location which is defined by the four cardinal directions. We will implement this to determine the relative positions of the Nucleo STM32F40REs in relation to each other. By utilizing the absolute (x, y) coordinates, based on NSEW, we can find the relative distances between them, allowing us to pinpoint their exact location.

2. **L2-Norm**: When we calculate the difference between our current location vector and the tracker's location vector, the L2-norm of this calculated difference gives us the distance between the receiver and the locator devices [33]. We will implement this algorithm to determine the distance between the 2 Nucleo STM32F40REs, as measured in metres. Using the NSEW coordinates, we can then use the norm to figure out the shortest path between the

two Nucleo STM32F40RE, which inturn gives us the distance between them as a single number.

$$||s_l - s_r|| = \sqrt{\sum_{i=1}^{2} (s_{li} - s_{ri})^2} \quad \dots (eq.\ 2)$$

The implementation of the scientific principle can be represented as the following algorithm:

```
int norm_L2(double[] dist1, double dist2) {
    double x_comp, y_comp, d;
    double norm{math.sqrt(math.pow(x2-x1) + math.pow(y2-y1))};
    while (norm > BUFFER){
        // Run until you get within the close enough (buffer range)
        x_comp = dist1[0]-dist2[0];
        y_comp = dist1[1]-dist2[1];
        // Calculate the difference for each component

        // Calculate the squares of the differences
        d = math.pow(x_comp) + math.pow(y_comp);

        // Calculate the distance between the two
        norm = math.sqrt(d);
    }
}
```

3. **Ohm's Law**: Due to the implementation of the LED and Piezo Buzzer, the use of Ohm's law becomes essential in preserving our components, as it allows us to determine how much resistance is to be placed in the circuit in order for each component to safely work [34]. This

will be implemented to ensure that nothing goes up in smoke in our circuitry. It plays a vital role in preventing short-circuiting and protecting both the components and our consumers.

$$V = I \cdot R \qquad \dots (eq.\ 3)$$

Where,

V - is voltage in Volts (**V**)

I - is current in Amperes (**C**)

R - is Resistance in Ohms (**Ω**)

Thus, using Ohm law, the LED which uses a voltage of 1.8V and the Buzzer, we can write:

$$R1 = (5V - 1.8V) / 0.002A = 160\Omega$$

$$R2 = 5V / 2A = 10K\Omega$$

3. Costs

3.1 Manufacturing and Implementation Costs

3.1.1 Bill of Materials

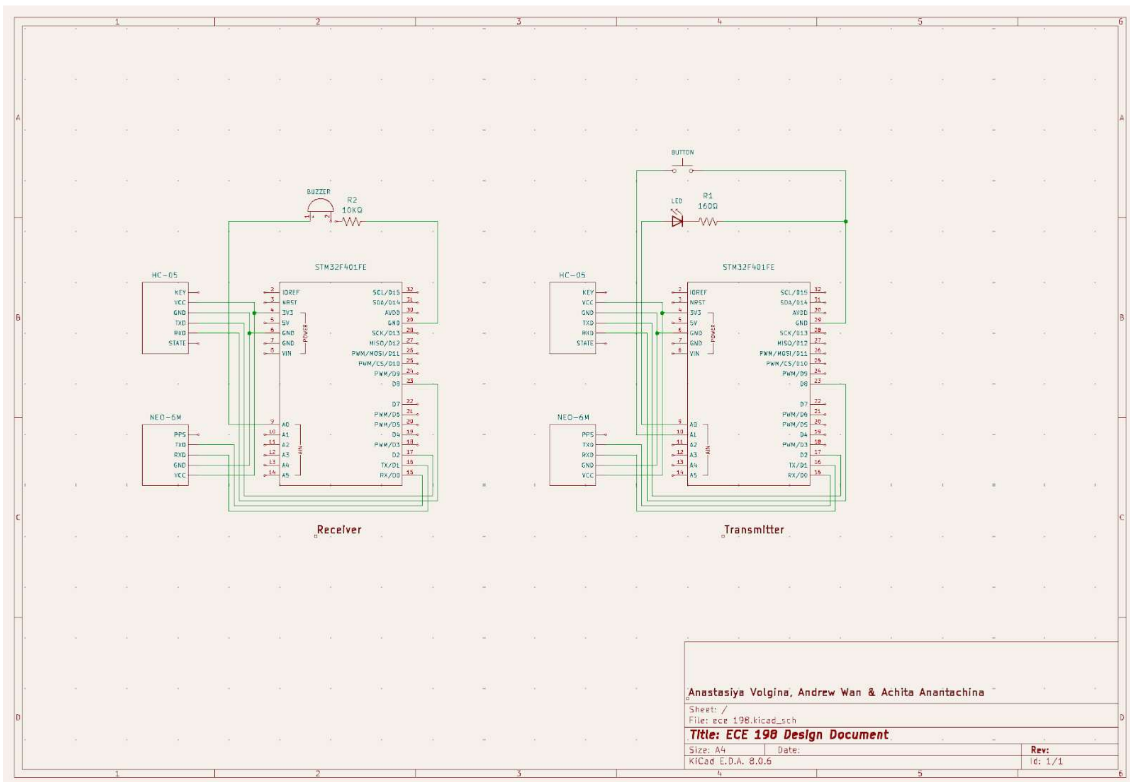
Part Name	Part Description	Quantity	Price	Manufacturers & Distributors
Nucleo STM32F40RE	Microcontroller used to process inputted information from sensors	2	\$20.31	Manufactured by STMicroelectronics (headquartered in Plan-les-Ouates, Switzerland) [35] Distributed by Digikey (based in

				Thief River Falls, Minnesota, USA) [35]
HC-05	Bluetooth to Serial Port Module used for communication between the two Nucleo STM32F40REs	2	$11.99	Manufactured by CSR plc (headquartered in China) [36] Distributed by CanadaRobotix (based in Toronto, Ontario) [36]
NEO-6M	GPS Module used to locate the longitude and latitude of the Nucleo STM32F40REs	2	$15.00	Manufactured by U-Blox (headquartered in Switzerland) [37] Distributed by MakerPortal (based in Manhattan, New York) [37]
Push Button	Button used to trigger the sound and LED system	1	$2.44	Manufactured by C&K (headquartered in Waltham, Massachusetts, USA) [38] Distributed by Digikey (based in Thief River Falls, Minnesota, USA) [38]
5mm LED	Red light emitting diode that will turn on when the Nucleo STM32F40REs are within 5m of each other	1	$0.47	Manufactured by Kingbright (headquartered in City Of Industry, California, USA) [39] Distributed by Digikey (based in Thief River Falls, Minnesota, USA) [39]

Piezo Buzzer	Speaker that can be remotely triggered to produce a sound on the WatCard locator device	1	$1.03	Manufactured by Murata Electronics (headquartered in Nagaokakyo, Kyoto, Japan) [40] Distributed by Digikey (based in Thief River Falls, Minnesota, USA) [40]
160Ω Resistor	Resistors of 160Ω used for LED, to prevent it from burning out	1	$0.16	Manufactured by Stackpole Electronics Inc (headquartered in Raleigh, North Carolina, USA) [41] Distributed by Digikey (based in Thief River Falls, Minnesota, USA) [41]
10KΩ Resistor	Resistor of 10KΩ used for piezo buzzer, to protect it from short circuiting	1	$0.16	Manufactured by Stackpole Electronics Inc (headquartered in Raleigh, North Carolina, USA) [42] Distributed by Digikey (based in Thief River Falls, Minnesota, USA) [42]
Total Cost: $98.86				

3.1.2 Installation Manual

This product will arrive fully assembled and operational. Store the devices in an area void of water and dust to prevent damage and wear to the parts [43]. During operation, this device should be kept in its shell to prevent harm to both the device and the user. In the event the wires are loose, they should be fixed based on the following schematic.



3.1.3 User Guide

After receiving the device, the setup is simple. The receiver Nucleo STM32F40RE stays on you at all times and the transmitter Nucleo STM32F40RE that will be stuck onto your WatCard. Once both are connected to a power source, the device will automatically start transmitting data and locate the other Nucleo STM32F40RE. The sound and light feature can be turned off and on using a small button. When you have lost your WatCard (with the Nucleo STM32F40RE attached to it), you click the button on the receiver Nucleo STM32F40RE and start to walk around. Once within range a sound should play, then a light should start to blink. Once the other Nucleo STM32F40RE along with the WatCard is located, click the button to again turn off the light and sound.

4. Risks

4.1 Energy Analysis

To provide a comprehensive analysis, we must first state the specifics and standards. We will be using the CSA reference standard for a baseline battery [44]. As stated by the Nucleo STM32F40RE development board datasheet, the Nucleo STM32F40RE has a power consumption of 300mA when 5V is being supplied. Likewise, the HC-05 Bluetooth Module has a power consumption of approximately 30mA during operation, but it can spike up to 50mA operating at a voltage ranging from 3.6V to 6V, but typically operating well at 5V [45]. NEO-6M GPS Module has a maximum power consumption of 67mA during operation, typically being powered at 3.3V [46]. The push button, one of the standards for projects involving microcontrollers, has minimal/negligible current while operating at 5V [47]. Next, the LED will use 20mA at 5V as determined in the Principles and Standards section of the report [48]. Finally, the Piezo Buzzer outputs typically around 5mA to 30mA with a Voltage of 5V being common in many circuits. As each component uses 5V, the total current drawn from the circuit can be calculated by the following:

I_total = *Current of Nucleo STM32F40RE board* + *Current of HC-05* + Current of NEO-6M GPS Module + *Current of LED* + *Current of Piezo Buzzer*

= 300mA + 50mA + 67mA + 20mA + 30mA

= 467mA

For the power consumption of the circuit, it be derived the following way:

Power = *Voltage* x *Current*

= 5V * 467mA = 2.335 Watts

Thus, the maximum power consumption of our design may not exceed 2.335 W at any instance.

In the design, the energy stored is minimal as in our design as there is no transfer of mechanical energy anywhere excluding the battery pack. Due to the fact that we have no capacitors, gravitational potential energy stored, or other power storage, the only two energy storage in our design is found in the capacitors on the microcontroller unit and the power source. As the capacitors on the microcontroller unit are small, the energy stored is considered negligible. Thus, the maximum total energy stored within our system is only given by our power source which in this case for the test is a USB 2.0 port from a desktop computer. If a battery is being used, the below formula would apply:

$$\mathbf{U} = \mathbf{V} * \mathbf{Q} = 5 \times 3600 \times (mah\ of\ battery) \text{ [49]}$$

Where,

U is the energy in Joules

V is the voltage in volts (5V)

Q is the charge in coulombs which is I (Current) * t (time)

Thus, the maximum stored energy in our system is less than 18 KJ and because no other energy storages have any other form of power, like potential or kinetic, the maximum cannot be higher than this.

Our project does not exceed any of the proposed project limits. Our design stores no energy, as we plug it directly into a USB 2.0 port, and it does use human test subjects.

4.2 Risk Analysis:

Given the proper implementation, there are minimal safety threats, although the tracking system can inadvertently cause issues with safety. Consider a person tracking their WatCard, due to the tracking device's design, it may cause people to follow the tracker into unsafe locations, distracting them from their surroundings, and possibly placing them in a dangerous position. Furthermore, depending on how the power is sourced, the energy consumed when using the design could be damaging to the environment. For instance, using normal batteries is already considered harmful to the environment [50].

On the other hand, if the design is implemented incorrectly, there could pose some safety risks for those near it, possibly due to high voltage currents or exposed wires. Additionally, there poses extreme environmental risks due to the waste of electronics, for instance. a LED. If we were to have connected the cathode and anode in the reverse way the LED would not run but the more jarring issue is if the incorrect resistor is inputted, in the worst case it can burn out the whole LED which leads to more waste [25, 26].

If the design is misused and the owner does not take the initiative to find their WatCard, then the device affects the environment due to the battery being left up in an open area can result in the leaking of hazardous compounds into the soil which could even possibly cause fires. Once again, the possible way the design could malfunction is due to the battery issue, if it is left out too long it causes damage to the environment. The design could also malfunction if the wires are loose [51].

In the event of a potential malfunction, due to the lower voltage and power stored within the device, damage would be minimal. If a software bug were to occur, in the worst case scenario the device would not work as intended and you would not be able to locate your WatCard. In most cases a software bug would just result in inaccuracies in locating a WatCard or potentially the device not working. If a hardware malfunction were to occur the device will most likely stop working. Since no battery is stored onboard and there are very small capacitors no fire or explosion would occur. Loose wires have the potential to cause a shock but again due to the low amounts of current and voltage, the damage should be minimal.

The environmental consequences for the aforementioned issues are hazardous materials leaking into the ground leading to the pollution of the soil around us. While the second one might not have any environmental issues, it still poses a great danger to humans.

5. Testing and Validation

1. A navigation update rate of 5Hz [21] to ensure it is sending up-to-date information on its location without expending too much power.

   We will test this by checking the runtime loop in the console and logging the timestamps (Using HAL_GetTick()). The timestamps should differ by exactly 200ms and should consistently send at that interval. In addition to just running this test in ideal conditions, we will re-perform this in a variety of different environments. This could include being on the move, when there are obstructions or differing battery voltages to ensure stability across a variety of different conditions. Once the log is generated we will analyse them by hand to confirm that the update rate is indeed 5Hz.

2. Locator device has a button that triggers a speaker on the WatCard holder, playing a chime at 70-85dB to help you locate it, but not any higher to lower the risk of ear damage [16].

   We will first test that a sound is produced when the button is pressed. We will then use Decibel X:dB Sound Level Meter [52] to make sure the sound level is within the acceptable range. Furthermore we will test in various locations and environments such as noisy ones, or when you have headphones on to confirm the sound can be heard. We will also test when the user is further away from the speaker as sound dissipates over distance to make sure that the sound can always be heard. This will be done a series of times to ensure consistent results.

3. Must be able to detect if the other Nucleo STM32F40RE is within 10m. This is the current range limit of bluetooth technology. [20]

   We will test this range feature of our device by setting the 2 Nucleo STM32F40REs exactly 10 m apart using a ruler. We will then turn the devices on to check and then check if the devices can detect each other by clicking the button and hearing if a sound plays. We will check the 10m tolerance both vertically and horizontally along with distance inside 10m (such as 5m, 8m etc) and slightly over 10m to ensure it guarantees it works within a 10m range.

4. As the person holding the locator device gets closer to the WatCard holder, the LED will start blinking once it reaches a distance threshold of 5m.

   We will test this by measuring out exactly 5 m with a rule then checking if the LED turns on. We will also test it both on a vertical and horizontal axis. After that we will test distances less than 5 m to ensure a working range of 5 m. To confidently ensure the range of 5 m we will also perform tests where the devices are slightly further than 5 m apart. This will both test the ranges and if the LED turns on.

5. The blinking speed of the LED increases inversely proportional to the distance (1/distance) between the WatCard holder and the locator device, but the blinking will not surpass 100 Hz as to reduce eye strain [18].

   We will test this by timing the blinking speed of the LED and comparing its inverse to the distance measured between the WatCard holder and the locator device. We will count the number of times the LED blinks in a designated interval of time (5 seconds), and calculate the average over the time interval; this process will be repeated 10 times for each distance, any outliers will be disregarded. We will make sure to test a variety of distances, ranging from 50cm to 5m, in 50cm interval increases. We will then repeat this test to ensure consistent results.

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