# Dog Training Collar

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ECE 445 Design Document - Spring 2020

## 1. Introduction

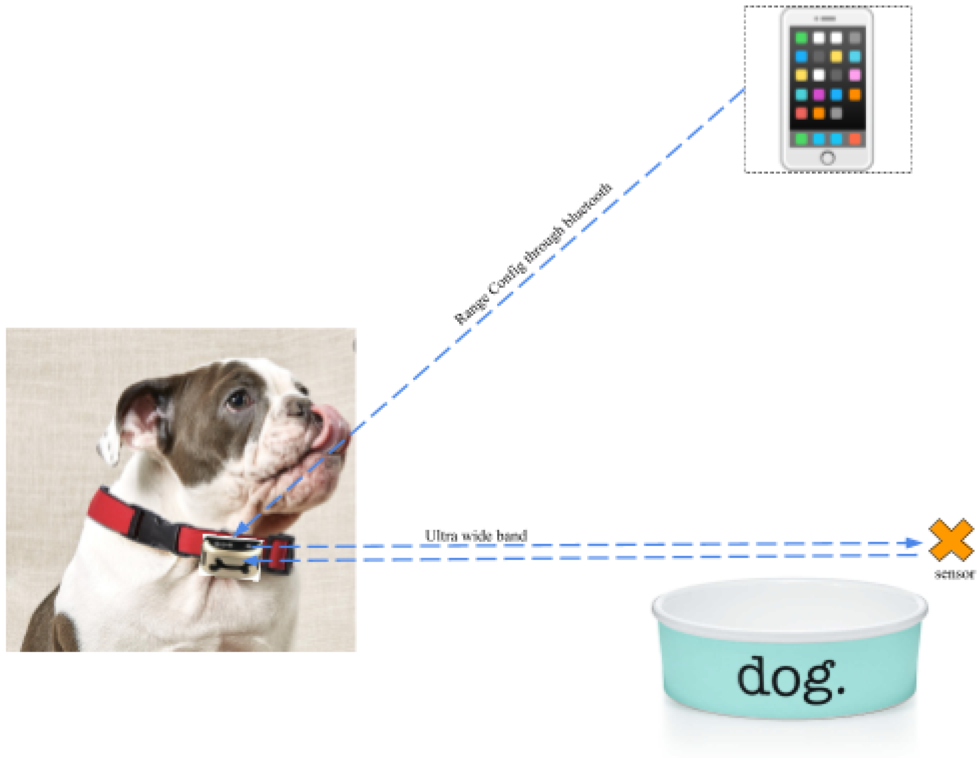
### 1.1 Problem and Solution Overview

Many dog owners face the problem of their dogs damaging or interacting with an object or area they shouldn't. For instance, dogs are often caught chewing electrical wires as well as accidentally running into vases, both of which may be disastrous. Owners of multiple dogs experience the trouble of keeping one dog away from the other's food, which may lead to malnutrition or obesity. When trying to keep their pets away from the area, dog owners find themselves in a helpless situation of scolding the dogs when they catch them in action, but to come home later to the same problem.

Thus, our solution is to train the dogs even without the presence of the owner to punish the dogs real time with a citronella spray. As the spray has been tested to be completely harmless to the animal, they have been a popular alternative to less humane products such as the shock collars. However, such products are either more notable in a punishment mechanism for barking (i.e. Petrainer 998DRB Remote Dog Training Collar) than as a training tool or controlled by a remote control (i.e. WWVVPET Citronella Dog Training Collar), making the presence of the owner a must.

We aim to target a similar but different problem as aforementioned, while increasing versatility when compared to competing products by using an UWB transmitter and receiver that will detect and spray the dog in the face when the dog is in the designated area and thus offering an effective training mechanism. We will also provide the users to set the range (10cm, 10m, 100m) of activation depending on their intention of use, which provides a more flexible service than the existing options.

### 1.2 Visual Aid



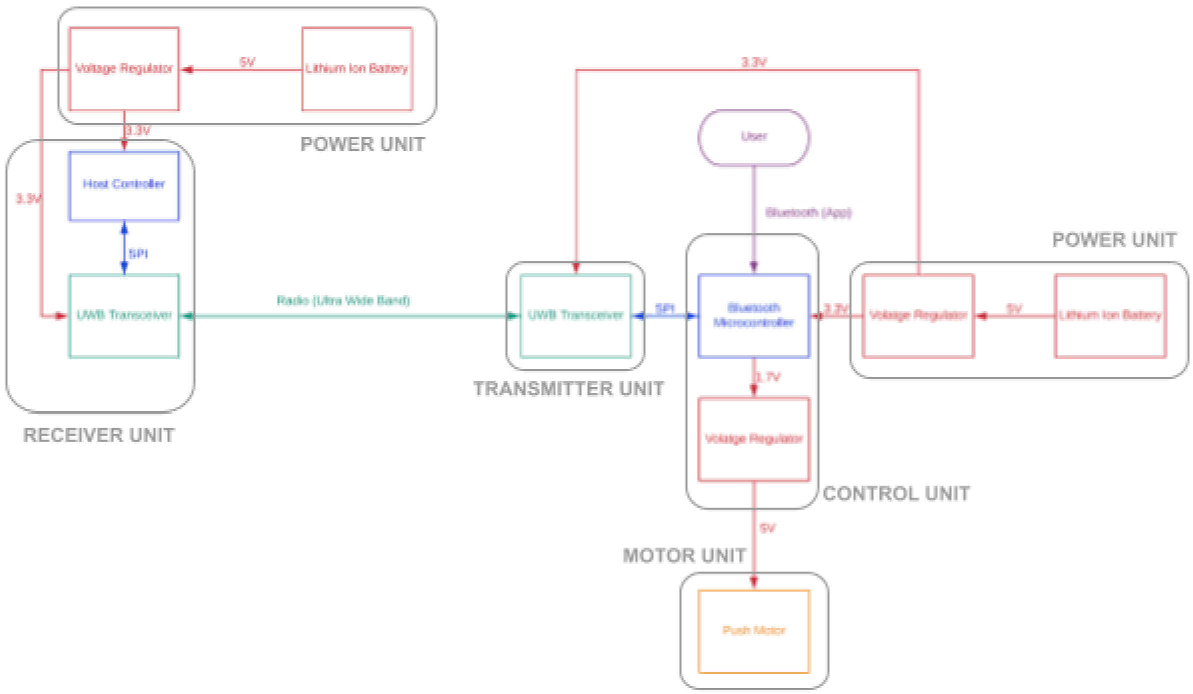

[Figure 1] UWB Interaction: Phone-Collar, Collar-Trans/Receiver

### 1.3 High-level requirements list

1. Distance measurement achieves a resolution of at least 15cm.
2. Spray diffuses short burst (0.2ml) of citronella liquid upon receiving an activation signal from the control unit.
3. Users can configure activation distance in 15cm steps from 10cm to 1m and receive confirmation via the app in less than 5 seconds.

## 2. Design

### 2.1 Block Diagram



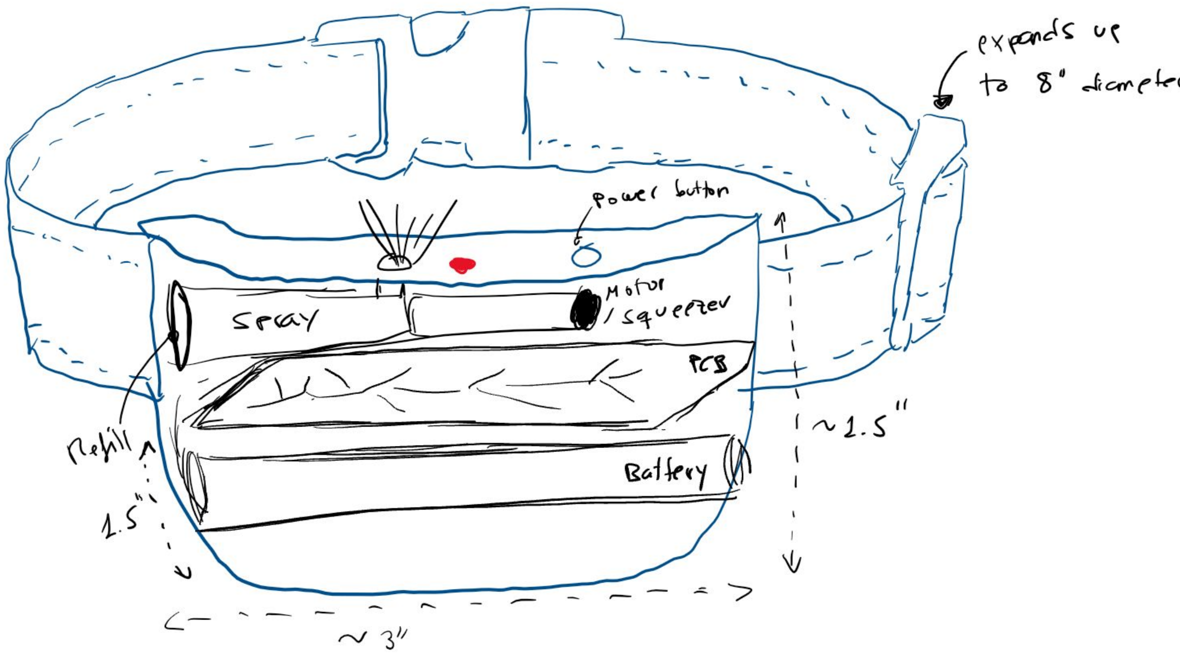

[Figure 2] Block Diagram: Transmitter/Receiver, Power, Motor, Control Units

The left-hand-side of the design would be the receiver and its power subsystem, which would be set up at the area to avoid, i.e. the other dog's bowl. This will consist of a UWB IC, antenna, and power supply (lithium ion battery). This block transmits and receives UWB packets to/from another UWB IC on the control unit to make a distance measurement. More details on this protocol and chip can be found in the subsystem section.

The spray subsystem will consist of a motor to be activated by the control unit, as well as a triangular reservoir with an output mist-spray nozzle that is pushed by the push motor.

The control unit block consists of the same UWB IC as mentioned as well as a bluetooth microcontroller. The bluetooth device will receive user input to set the activation range of the spray subsystem, and will maintain a SPI connection with the UWB IC to receive a distance measurement.

## 2.2 Physical Design




[Figure 3] Physical Design of Collar

The diagram shows a physical realization of the collar system. We can see a regular dog collar (slightly bigger and adjustable) with the device location in the front. The plastic exterior of the device boxes are all the components: spray tube with corresponding motor; PCB with circuits and communication modules (Bluetooth microcontroller, UWB IC); a lithium ion battery. The dimensions on the sketch are approximations and will be downsized if possible.

## 2.3 Subsystems

| Subsystem/Component | Physical Req. | Electrical Req. | Verification procedure |
|---|---|---|---|
| Motor | Not exceeding 4in in length, 1.5in in diameter | - 5V nominal voltage<br>-Current and power to be determined based on force necessary for pump | -Voltmeter to measure supplied voltage<br>-Sensitive multimeter to measure current and then power consumption<br>-Measuring tape for |

| | | | |
|---|---|---|---|
| | | | physical specs |
| Pump/reservoir | Not exceeding 4in in length, 1.5in in diameter | -Force necessary not exceeding that supplied by a 3.3V motor with given physical reqs | -Measure force by placing increasing weight on the nozzle (FMS)<br>-Measuring tape for physical specs |
| DW1000 Transceiver | 6x6mm | - 2.8 V to 3.6 V (3.3 Typical)<br>- 19mA in IDLE mode<br>- 30 mA in RX/TX mode<br>-Average power consumption: 79uA | -Voltmeter to measure supplied voltage<br>-Sensitive multimeter to measure current |
| Cover | 38x38x76mm | N/A | Fill inside of case with a few of the citronella spray.<br>Spray the case with water from a 12.5mm nozzle from 3 meters, for 3 minutes<br>Shake case thoroughly |
| Bluetooth microcontroller (nRF52832) | 6x6mm | -1.7~3.6V supply voltage required | -Voltmeter to measure supplied voltage |

[Table 1] Component High Level Requirements

### *2.3.1 Control Unit*

This unit is responsible for interfacing with the two ultra wide band chips in our device as well as communicating with the user. The control unit PCB contains the mainly transmitting module and bluetooth microcontroller user-interface which use SPI to send and receive timestamp and frequency data that are critical in estimating the range at which the spray subsystem will be activated.

***Bluetooth microcontroller:***

The user-interface module will be an nRF52832 module or similar. This is a bluetooth enabled SoC containing an ARM M0 core and on-chip memory. This module is capable of receiving bluetooth packages containing data from the user's mobile app. These will contain user settings for configuring the range at which the spray will be triggered using the time of flight of the receiver's acknowledgement packets to get to the transmitter. This module must also maintain a serial connection with the UWB IC to receive and compare distance measurement with the user data.

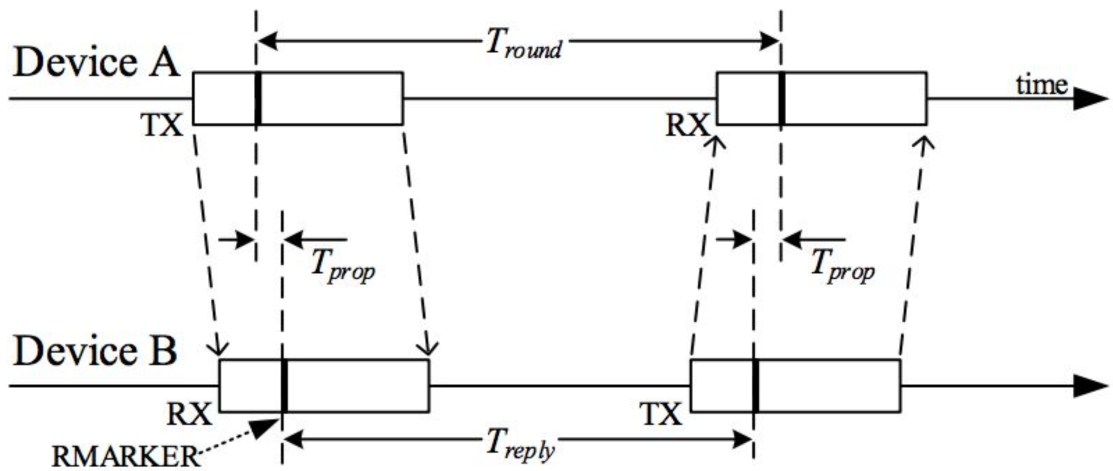
| Requirement | Verification |
|---|---|
| - Must support SPI interface as external host (general-purpose processor)<br>- Must be powered by a low voltage below 3.3V (lithium-ion battery).<br>- Must support minimum 0.27 Mbps throughput (low-end BLE) | - ARM core should function as an external processor as designed. If write data is received by the UWB IC then the functionality is verified.<br>- Bluetooth microcontroller has configurable throughput, again should function as designed based on datasheet. |

Calculation **[1]**:

- BLE packet contains at maximum 20 Bytes of actual app-data, remainder contains metadata, bookkeeping etc
- High-level requirement of 15cm-10m activation range with steps of 15cm → ~67 distinct user values to encode → can be stored in less than a byte of data
- Since the user will in practice change settings at a slow rate from hardware perspective, very low throughput will suffice.

***Transmitter DW 1000 Chip:***

The transmitter unit will be an UWB IC. The transmitter unit and receiver unit will together implement a protocol known as single-sided two-way ranging (SS-TWR). **[2]**




[Figure 4] Single-sided Two-Way Ranging Protocol

When a packet is sent by the initiator (TX), it is timestamped. Similarly, the packet is also timestamped by the receiver upon arrival. When the packet is sent back and timestamped again by each device, the reply time and round-trip time can be computed independently. Because both $T_{reply}$ and $T_{round}$ are computed with respect to each device's local clock, synchronization is unnecessary. The propagation time can then be estimated as below.

$$T_{prop} = \frac{1}{2}(T_{round} - T_{reply})$$

[Eq. 1] Propagation time for SS-TWR

Error in distance estimation increases as $T_{reply}$ grows large, so it is possible that we may implement double-sided two way ranging, an improvement on the above method that requires an additional round-trip of a second packet. Even with 20ppm clock drift, a distance resolution of up to 2.2mm with a range of 100m is attained (DW1000 User Manual).

When the protocol completes, the transmitter module will send a distance estimation to the user-interface microcontroller via SPI.

| Requirement | Verification |
| --- | --- |
| - Must transmit data packets to Bluetooth microcontroller at less than 8^28 Mbps (max value set for SPI slave by nRF52832) | - For all requirements listed, the chip will function as intended if the device meets specifications of the datasheet. **[2]** |

| | |
|---|---|
| - Must support at least 6GHz RF band<br>- Must be powered by a low voltage at or below 3.3V (lithium-ion battery). | |

Current Consumption:

1. In Mode 4 (6.8Mbps data rate), DS-TWR protocol
    a. 173*2 = 346 µs to complete packet path
    b. Draws average of 67 mA current
2. In SLEEP state, draws 2 µA current for 300ms between wake-ups
3. Then average current consumption = 67mA*(.346ms/(300.346ms) + 2µA*(300/300.346) = 79 µA

### *2.3.2. Receiver unit*

As aforementioned, the receiver module will consist only of a UWB IC and power supply. The requirements and use of this module have been specified in the above section. Since the UWB IC needs to be connected to a master controller to function as a slave, we will use a generic microcontroller LPC8N04FH124E. The receiver does not need to send measurement data to an external processor, but does need to maintain an SPI interface with logic/state machine that will trigger transmission of packages.

***Receiver DW 1000 Chip:***

| Requirement | Verification |
|---|---|
| - Must support at least 6GHz RF band<br>- Must be powered by a low voltage at or below 3.3V (lithium-ion battery). | - For all requirements listed, the chip will function as intended if the device meets specifications of the datasheet. **[2]** |

Current Consumption **[2]**:

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3. Then average current consumption = 67mA*(.346ms/(300.346ms) + 2µA*(300/300.346) = 79 µA

***Host Controller:***

| Requirement | Verification |
|---|---|
| - Must support slave SPI communication<br>- Must be powered by a low voltage at or below 3.3V (lithium-ion battery).voltage | - For all requirements listed, the chip will function as intended if the device meets specifications of the datasheet. **[3]** |

### *2.3.3 Spray Subsystem*

The spray unit will consist of a 1mL glass fine mist sprayer(0.3" diameter, 2.3" height) and a push motor attached to the nozzle. The unit must respond to a high voltage asserted on the activation line, specifically on the rising edge of the signal.

***Push Motor:***

To implement such a spray unit, we will use a motor similar to ROB-11015 to implement the push movement.

| Requirement | Verification |
|---|---|
| - 5±5% VDC voltage supply.<br>- Sufficient current/power to push spray nozzle (1.1A at 5V) | - Attach one end of the multimeter to voltage regulator output and the other to the push motor<br>- Ensure output voltage remains between 4.75~5.25V<br>- Attach spray nozzle to push A Motor to verify the motor supplies enough power to spray the liquid |

### 2.3.4 *Power Subsystem*

Two lithium-ion batteries, voltage regulators, and an accompanying power bus will drive the circuitry in both the control unit, transmitter/receiver, and spray subsystem.

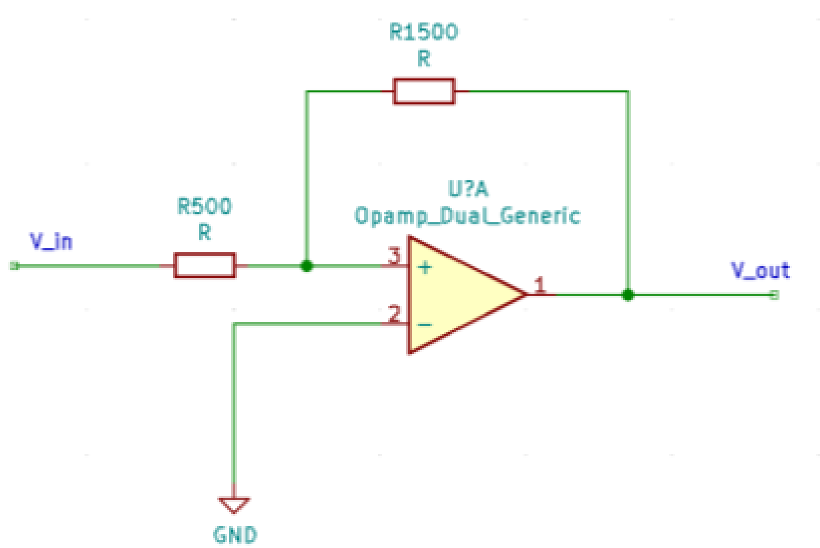
***Lithium-ion Battery:***

| Requirement | Verification |
|---|---|

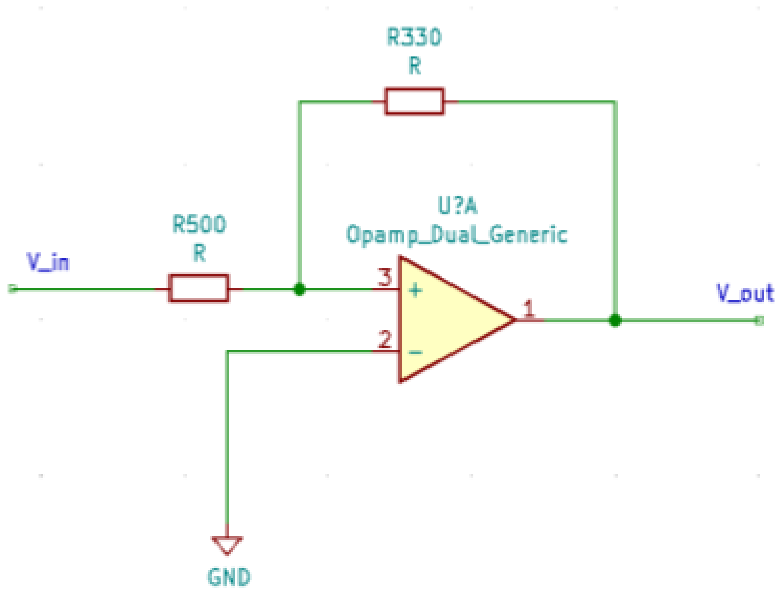
| | |
|---|---|
| - Must be able to provide a steady 5±5% VDC power supply to the control, transmitter, and receiver units or their corresponding voltage regulators. **[4]** | - Attach one end of the multimeter to battery output and the other to the voltage regulator input<br>- Ensure output voltage remains between 4.75~5.25V |

***Voltage Regulator:***

We will use a voltage regulator to provide each unit with a voltage supply sufficient to power the each device. In particular, we plan to use the Op Amp circuit that is capable of supplying a 1.8-6.0V range as well as a 100µA current. Since the Bluetooth Microcontroller, Transmitter, Receiver, Host Controller units require a voltage of 1.7~3.6V and the push motor requires a 5±5%V supply, the chip suffices all requirements.

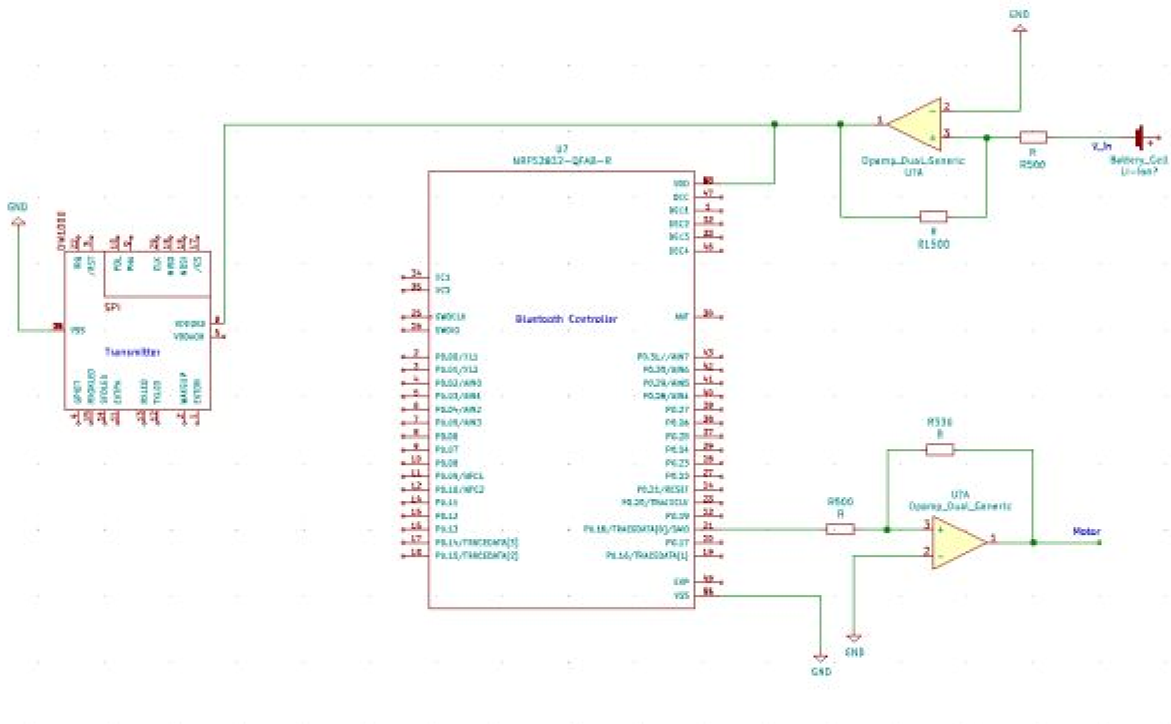



[Figure 5] Voltage Amplifying Op Amp (Voltage Regulator to Push Motor)




[Figure 6] Voltage Dividing Op Amp (Voltage Regulator to Microcontroller/Transmitter/Receiver)

| Requirement | Verification |
|---|---|
| - Must convert a 5~5.5V input voltage from battery to ~3.6V to supply Bluetooth microcontroller, transmitter, receiver, and host controller units.<br><br>- Must convert 1.7V output voltage from the Bluetooth microcontroller to supply a 5V voltage to the push motor. | - Measure V_in using a multimeter connected in parallel.<br>- Measure V_out using a multimeter connected in parallel.<br>- Ensure V_in measures between 4.75~5.25V<br>- Ensure V_out measures between 3.14~3.47V<br><br>- Measure V_in using a multimeter connected in parallel.<br>- Measure V_out using a multimeter connected in parallel.<br>- Ensure V_in measures between 1.66~1.83V<br>- Ensure V_out measures between 5~5.25V |




[Figure 7] Transmitter, Control Units with respective Voltage Regulators

### 2.3.5 *Collar Device*

For the collar, we are going to use a regular dog collar with the strength to hold the weight of our system. The transmitter, control and power unit, and the liquid reservoir will be placed inside an IP66 enclosure to guarantee the IP66 requirements. Thus it is important to prevent reservoir leakage inside the enclosure to avoid safety issues.

***Spray Reservoir:***

| Requirement | Verification |
|---|---|
| - Meets IP66 environmental code<br>- No leakage from spray nozzle or reservoir despite dog's physical movement | - Fill reservoir with nozzle with liquid<br>- Shake enclosure steadily and check interior of structure for any liquid |

## 2.4 Tolerance Analysis

The most important and critical part of our device would be using the internal timestamp differences to calculate the distance at which the spray will be activated using SS-TWR as described in Figure 5. Since the timestamp difference would be multiplied by the speed of light, it is critical that we guarantee minimal error in the time of flight estimation. Such an error has been guaranteed to be very little by the user manual**[7]** of DW1000 IC as explained below.

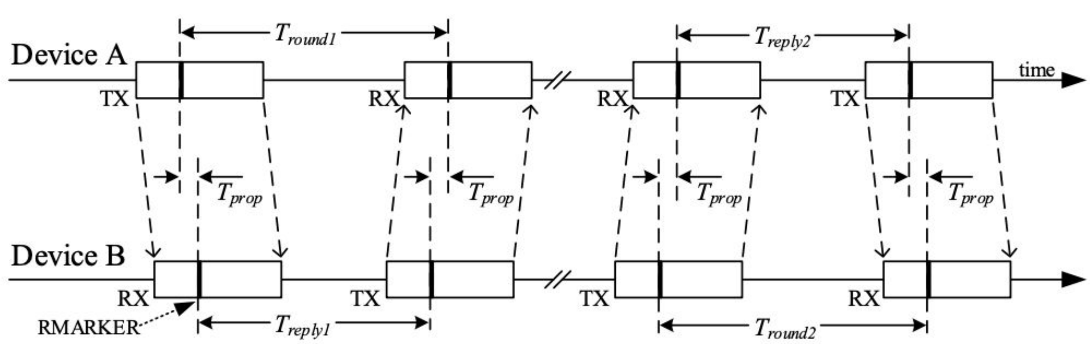
| clock error / $T_{reply}$ | 2 ppm | 5 ppm | 10 ppm | 20 ppm | 40 ppm |
|---|---|---|---|---|---|
| **211 µs total**<br>6.81 Mbps<br>64 Symbol Preamble<br>96 µs response delay | 0.2 ns | 0.5 ns | 1.1 ns | 2.1 ns | 4.2 ns |
| **275 µs total**<br>6.81 Mbps<br>128 Symbol Preamble<br>96 µs response delay | 0.3 ns | 0.7 ns | 1.4 ns | 2.8 ns | 5.5 ns |
| **403 µs total**<br>6.81 Mbps<br>256 Symbol Preamble<br>96 µs response delay | 0.4 ns | 1 ns | 2 ns | 4 ns | 8 ns |

Note: An error of 1 ns is equivalent to a 30 cm error in measured distance.

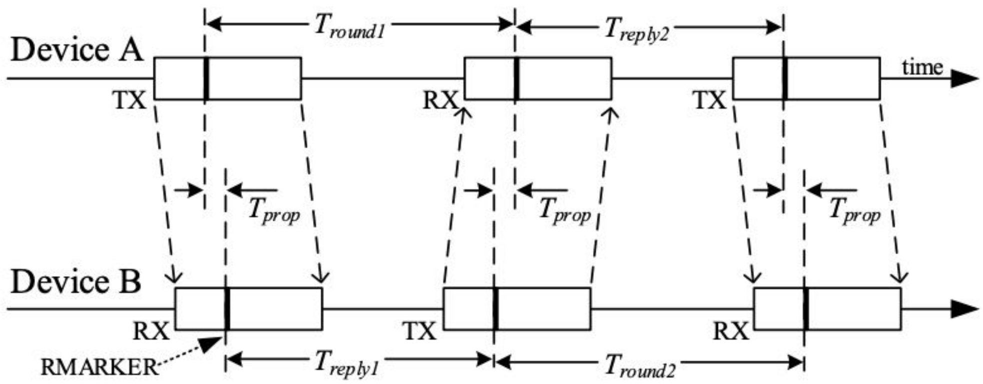
[Figure 8] T_reply vs Clock Error from DW1000 User Manual

As specified above, a clock error of 1ns results in a distance measurement error of 30cm. With an accurate crystal clock, the error would be much less.

There are other ways that we can implement to further reduce the error. Double-sided Two-way Ranging using 3 or 4 messages can reduce the time of flight error to as low as a picosecond range with 20ppm crystals using the equation 2.




[Figure 9] Double-sided Two-way Ranging using 4 messages




[Figure 10] Double-sided Two-way Ranging using 3 messages

$$\hat{T}_{prop} = \frac{(T_{round1} \times T_{round2} - T_{reply1} \times T_{reply2})}{(T_{round1} + T_{round2} + T_{reply1} + T_{reply2})}$$

[Eq. 2] Propagation Delay Calculation for DS-TWR

# 3. Cost and Schedule

## 3.1 Cost Analysis

The average starting salary of an undergraduate from UIUC is $78,159. The average working hours for a first year engineer per year is 1920, assuming a 40-hour week (eight hours a day, five days a week) minus 160 hours of vacation . Therefore, development costs are estimated to be $40.7/hour, 10 hours/week for three people. We consider approximately 85% of our final design in this semester (16 weeks). Finally, the total fixed development cost is $23k.

Furthermore, the manufacturing cost of our prototype must be considered too. Apart from all the materials and pieces we are going to need, we will include a small percentage for any contingencies that we can find throughout our semester as well as some additional units in case some stop working:

| Part | Manufacturer | Units | Cost ($) | Total ($) |
|---|---|---|---|---|
| DW1000 | Abracon Corp. | 2 | 10.92 | 21.84 |
| Antenna | Taiyo Yuden | 3 | 2.2 | 6.6 |

| | | | | |
|---|---|---|---|---|
| Case | Polycase | 1 | 14.5 | 14.5 |
| Motor | SparkFun | 1 | 4.95 | 4.95 |
| Pump/reservoir | Amazon/generic | 1 | 1.59 | 1.59 |
| Spays | PetSafe | 2 | 11.95 | 23.9 |
| Host (BTH) | Nordic | 2 | 5.46 | 10.92 |
| PCB | Machine Shop | 2 | 3.10 | 6.2 |
| Li-ion battery | Panasonic | 2 | 9.8 | 19.6 |
| Crystal (CLK sync) | Abracon Corp. | 2 | 0.98 | 1.96 |
| Collar | Chewy.com | 1 | 5.99 | 5.99 |
| LED for Collar | Machine Shop | 2 | 0.69 | 1.38 |
| Contingencies | N/A | N/A | 25 | 25 |
| Op Amp | Microchip Tech. | 3 | 0.33 | 0.99 |
| | | | **TOTAL** | 145.42 |

### 3.2 Schedule

| Week | Jihyun | Louis | Gonzalo |
|---|---|---|---|
| 02/24/20 | Find suitable spray system and motor | Find suitable communication system | Find suitable hosts for control and app design |
| 03/02/20 | Buy components | Design PCB Layout | Design application |
| 03/09/20 | Buy components and replacements | Ask Machine shop for custom PCB | Start programming application |
| 03/16/20 | Test motor and spraying system | Assemble first components to PCB Test PCB design and basic requirements. | Assemble first components to PCB Test antennas |
| 03/23/20 | Apply improvements | Test application and | Monitor latency and |

| | | | |
|---|---|---|---|
| | to spraying system | communication between UWB | time requirements for all communications and range accuracy |
| 03/30/20 | Improve UWB distance measurement processing | Continue work on data transmission | Test power requirements for the system |
| 04/06/20 | Integrate prototype | Integrate prototype | Integrate prototype |
| 04/11/20 | Combine all pieces with the collar and case | Test system on real dog | Test for IP66 case resistance |
| 04/20/20 | Prepare final report | Prepare final report | Prepare final presentation |
| 04/27/20 | Prepare final presentation | Prepare final presentation | Prepare final presentation |

## 4. Discussion of Ethics and Safety

The most important relevant IEEE Code of Ethics**[5]** in the context of our project is the first, which states that our device must prioritize the safety and health of the consumer and the environment. Citronella oil is a well-studied and widely used product. According to the FDA, the product has been classified as GRAS (generally recognized as safe), and sees use as insect repellent and in dog training products such as other citronella dog spray collars.**[6]** The spray's scent is offensive to dogs and other animals, but not dangerous. Furthermore we hold that our product is ethical in that it does not cause lasting psychological or emotional damage to the animal. Exposure is brief and is only surprising or at worst unpleasant to the dog. Our product compares favorably to shock collars for instance, which are legal but results in brief but sharp pain. Possible safety concerns mostly arise from the housing unit for our device. If this unit is not secure and subsystems are dislodged such as the power unit, reservoir, or other small parts, there is a risk of choking hazard for small children or the dog. Emphasizing build quality in our design will be crucial to avoid these issues. In the development of the product, we will make sure to follow the seventh IEEE Code of Ethics**[5]** and openly accept honest criticism of other group members and course staff to help better the design of the product and not take credit of those whose work was involved in the progress. We will also respect all involved so that everyone is respected and not discriminated based on factors implied in the 8th IEEE Code of Ethics**[5]**. The project will involve no injuries caused due to malicious behavior according to the 9th Code**[5]** and keep a professionally supportive environment for all colleagues involved by the last Code of Ethics**[5]**.

## 5. Citations

[1] *nRF52832 Bluetooth v4.2 module.* nRF52832 Datasheet. Nordic Semiconductor ASA. (2017-10-10). Retrieved from: https://infocenter.nordicsemi.com/pdf/nRF52832_PS_v1.4.pdf

[2] *DW 1000 Radio IC.* DW1000 Datasheet. Decawave Ltd 2015. Version 2.09. Retrieved from: https://www.decawave.com/sites/default/files/resources/dw1000-datasheet-v2.09.pdf

[3] *32-bit ARM Cortex -M0+ microcontroller.* LPC8N04 Datasheet. NXP Semiconductors. Rev. 1.4 - (2018-6-8). Retrieved from: https://www.nxp.com/docs/en/data-sheet/LPC8N04.pdf

[4] *Lithium-Ion Battery.* NCR18650BF Datasheet. Panasonic. Retrieved from: https://b2b-api.panasonic.eu/file_stream/pids/fileversion/3446

[5] 7.8 IEEE Code of Ethics. (2004). *IEEE Policies, Section 7 - Professional Activities (Part A - IEEE Policies).* Retrieved from: https://www.ieee.org/about/corporate/governance/p7-8.html

[6] Code of Federal Regulations Title 21. (Apr. 1, 2019). *Department of Health and Human Services. Subchapter B -- Food For Human Consumption.* Retrieved from: https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?cfrpart=182&showfr=1

[7] *DW 1000 Radio IC.* DW1000 User Manual. Decawave Ltd 2015. Version 2.09. Retrieved from:https://www.decawave.com/sites/default/files/resources/dw1000_user_manual_2.11.pdf?fbclid=IwAR3kuqh6ElrlnjfWNQE1BP7qutd5mbNjfpVBKMCRqsPVk-5f-4H_9w4Wk6w