Cheap, Accurate, and Privacy Preserving Contact Tracing Chip

ECE 445 Design Document

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1 Introduction

1.1 Objective

COVID is a deadly and highly infectious disease, and given the current trend of globalization and environmental destruction, such pandemics will only become more common. Testing and contact tracing are one of the best ways to fight a highly infectious disease while allowing people to maintain some semblance of a normal life. Contact tracing is becoming a rapidly heavily adopted way of fighting pandemics and is being used by the CDC in the United States [1].

We propose a small, cheap chip that can be easily carried which will automatically communicate with other nearby chips over ultra-wideband (UWB) to perform contact tracing, detecting potential transmissions of up to 10 feet away (adjustable depending on the nature of the pandemic it is being used for). Additionally, it must be regularly docked with a PC with Internet access to charge and upload contact information to a server. While there are existing solutions that use smartphones, these solutions are less than ideal for reasons that will be outlined below.

1.2 Background

Current contact tracing solutions either rely on manual effort, or mobile apps, which are both flawed. Manual methods typically involve calling someone who has tested positive and asking them to recall whom they met, which obviously is highly imperfect, since people oftentimes provide insufficient information, and many contact tracers must be hired [2].

Mobile contact tracing apps, although a great improvement over manual contact tracing, still have serious flaws. Apps that use GPS suffer from the fact that GPS is not always available and also quite inaccurate, not to mention the privacy concerns of mass surveillance of everyone's locations. Apps that use NFC, or Bluetooth, to address the privacy and availability concerns of GPS, still fall short. In the case of NFC, the range is far too small, and in the case of Bluetooth, the ability to measure distance accurately is sorely lacking, which inevitably leads to high false positive rates [3]. Finally, modern smartphones are simply too expensive in many parts of the world, and few people have sufficiently sophisticated smartphones that can perform effective contact tracing. This chip will allow people without smartphones to carry something cheap and effective in the fight against infectious disease.

2 High Level Requirements

- The chance of a false negative, which is defined as the device failing to record a contact despite two users being less than 10 feet apart, must be less than 25%. The chance of a false positive, which is defined as the device recording a contact despite two users being more than 10 feet apart, must be less than 25%.

- The device must be capable of operating for at least 12 hours without having to be charged.

- The protocol must provably prevent malicious attackers from faking a positive status. It must also provably prevent anyone with access to the server from deducing any individual's identity, without access to additional information, such as when any given user tends to connect to the server. This property can be formally proven, assuming a bug-free implementation.

3 Block Diagram

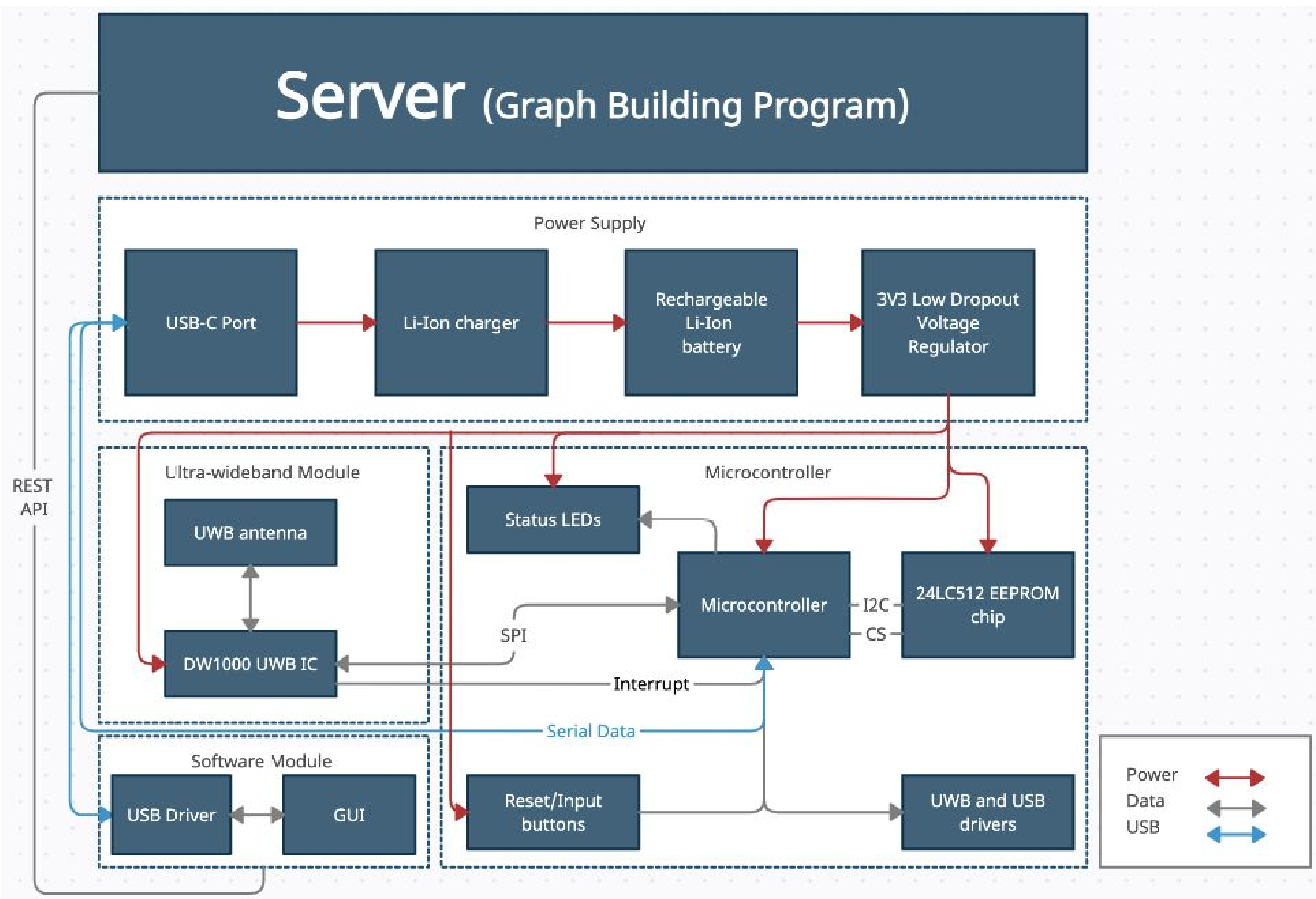

Figure 1: Block Diagram

4 Physical Design

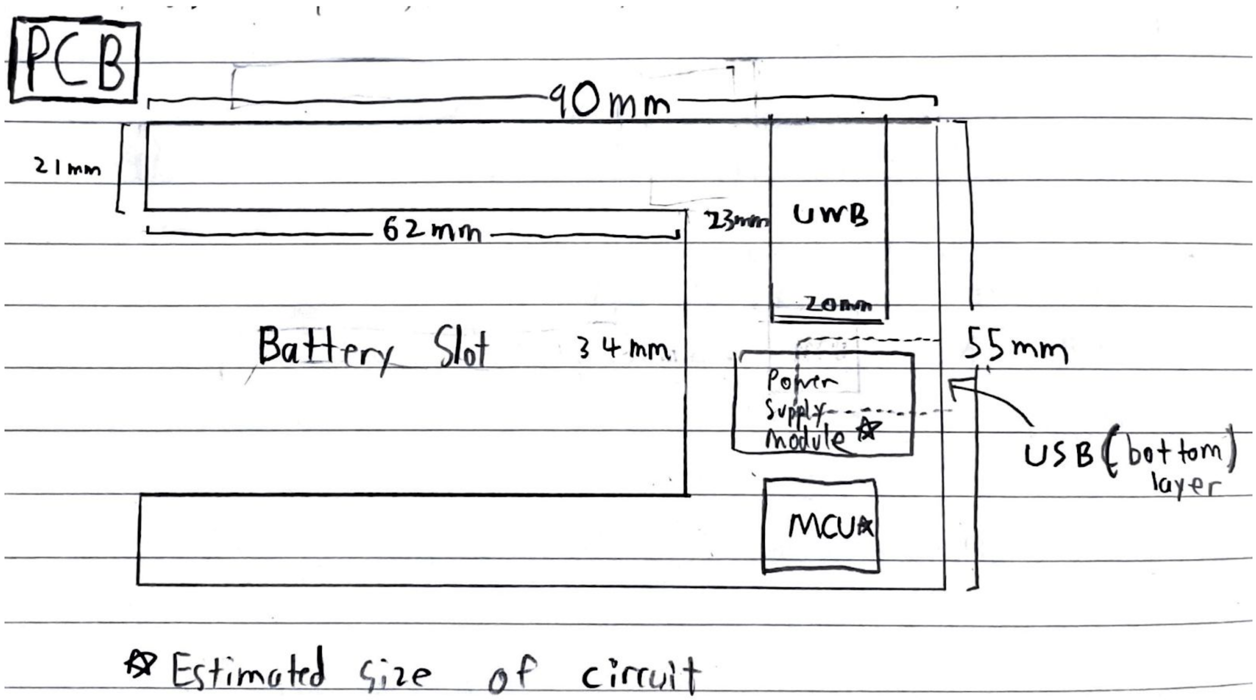

Figure 2: Physical Design of PCB

5 Requirements & Verification Tables

5.1.1 Ultra-wideband Module

Requirement	Verification
1. Determine distance between two separate modules with a precision of at least 10cm so that false positives and false negatives are reduced. 2. Ranging error within 10% of actual distance	1. A. Connect two separate UWB modules to two separate Arduinos acting as mock object B. Upload test firmware to send simple data packets back and forth C. Physically distance each node with a known distance. Increment from 1 to 10 meters 2. A. Record measured distance from actual distance B. Ensure error within 10%

5.1.2 Li-Ion Charger

Requirement	Verification
1. Lithium ion battery charges to a full 4.2V when charged from USB 2. Reaches full charge safely from a 5V, 500mA input within 3 hours	1. A. Discharge lithium ion battery to 3.7V B. Charge the battery from MCP73833 Li-Ion charging IC with USB input 2. A. Check battery is charged to 4.2V at the end of 3 hours

8 Tolerance Analysis

in order to ensure that we keep the chance of false negatives and false positives below 25%, we must perform some statistical analysis. Treating the UWB chip as a black box which can return an estimated distance value based on some probability distribution, we can determine the number of repeated measurements necessary to achieve the desired rate of false reports. In order to minimize power consumption to reach our battery life requirement, it is critical that we keep the number of repeated measurements as low as possible.

Define $P_d(x)$ as the probability density function over the estimated distance value x given an actual distance of d. Define T as the contact threshold, which in this case is 10 feet. Define n as the number of measurements we must make before deciding whether a contact occurred or not. Finally, define ρ as the desired maximum failure probability, which is 25%.

We can make the following reasonable simplifying assumptions on the probability distribution, given, without loss of generality, a < b

Assumption 1 - If $x_1 > b$

$$\int_{x_1}^{x_2} P_a(x)\,dx < \int_{x_1}^{x_2} P_b(x)\,dx$$

Assumption 2 - If $x_2 < a$

$$\int_{x_1}^{x_2} P_a(x)\,dx > \int_{x_1}^{x_2} P_b(x)\,dx$$

In plain English, this means that if the actual distance goes up from a to b, the probability density for the estimated distance also shifts upwards, as well as the converse, respectively. This assumption is very basic and likely holds even for inferior alternatives to UWB like Bluetooth, NFC, and audio.

We can state our requirements for false negatives and positives as the following, respectively

- For all $d < T$

$$\left(\int_{T}^{\infty} P_d(x)\,dx\right)^n < \rho$$

- For all $d > T$

$$\left(\int_{0}^{T} P_d(x)\,dx\right)^n < \rho$$

Using **Assumption 1** and **Assumption 2**, respectively, we can conclude the following

$$\forall d < T : \left(\int_{T}^{\infty} P_d(x)\,dx\right)^n < \left(\int_{T}^{\infty} P_T(x)\,dx\right)^n$$

$$\forall d > T : \left(\int_0^T P_d(x)\,dx\right)^n < \left(\int_0^T P_T(x)\,dx\right)^n$$

This means that as long as we can find a value n such that the false positive or false negative rate at $d = T$ stays below ρ, by transitivity, we know that this holds for all d. All that remains to be done, then, is to perform measurements to characterize the probability distribution $P_T(x)$.

Assuming a symmetric distribution (and assuming the variance is small enough that the tail can be effectively ignored), the integral of $P_T(x)$ from 0 to T and from T to ∞ is 50%. Therefore, to achieve a false positive / negative rate of 25%, we simply have to find the smallest integer n such that $50\%^n < 25\%$, which gives a value of exactly $n = 2$. Although the real probability distribution is likely not symmetric, the final result will probably not be far from this estimate.

9 Ethics and Safety

A project of this nature has various ethics and safety concerns. Starting with ethics, the primary concern is user privacy and the storage of personal data. As #1 from the IEEE Code of Ethics states, we must "hold paramount the safety, health, and welfare of the public… [and] protect the privacy of others" [4]. In this case, our project aims to satisfy both of these apparently competing goals. Typical contact tracing solutions sacrifice individual privacy to protect the "safety, health and welfare" of others. Our solution, however, stores data using completely anonymous and randomly generated IDs, and so protects user privacy.

Additionally, #9 from the IEEE Code of Ethics states that we must "avoid injuring others, their property, reputation, or employment" [4]. In this case, our solution has the potential to damage others' employment and personal happiness by forcing them to quarantine or by giving them a false sense of confidence. In order to minimize these risks while maximizing public safety, we have established a minimum probability of false contacts to balance the two competing interests consistently and ethically. We also will prevent the possibility of malicious actors with forged COVID statuses by requiring that COVID statuses be cryptographically signed by trusted testing centers.

Our project also has a few, albeit relatively minor, safety concerns. Since we are using lithium-ion batteries, there is a possibility of fire or explosion under a couple of circumstances: physical damage to the battery, high temperatures above 130°F, and below freezing temperatures during charging [5]. According to OSHA recommendations, in order to minimize the risk of fire or explosions, we must store the batteries in cool, dry locations, avoid physical damage, stop using upon any sign of bulging or high temperature, and remove batteries from the charger once they are fully charged [5]. Additionally, we must have an emergency action plan (EAP) for what we should do if anything goes wrong, which we have sufficient information for from the lab safety training [5].

References

[1] “Contact Tracing Steps - Infographic.” Centers for Disease Control and Prevention, Centers for Disease Control and Prevention, 26 Feb. 2021, www.cdc.gov/coronavirus/2019-ncov/daily-life-coping/contact-tracing-infographic.html.

[2] D. Lewis, “Why many countries failed at COVID contact-tracing - but some got it right,” *Nature News*, 14-Dec-2020. [Online]. Available: https://www.nature.com/articles/d41586-020-03518-4. [Accessed: 01-Mar-2021].

[3] R. Faragher, “The Hidden Trade-Offs Inside Contact-Tracing Apps,” Forbes, 22-Apr-2020. [Online]. Available: https://www.forbes.com/sites/ramseyfaragher/2020/04/21/the-hidden-trade-offs-inside-contact-tracing-apps/?sh=dd085eeea07a. [Accessed: 01-Mar-2021].

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[5] “UNITED STATES DEPARTMENT OF LABOR,” *Safety and Health Information Bulletins | Preventing Fire and/or Explosion Injury from Small and Wearable Lithium Battery Powered Devices | Occupational Safety and Health Administration*. [Online]. Available: https://www.osha.gov/dts/shib/shib011819.html. [Accessed: 01-Mar-2021].