Smart Keys/Key box

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ECE 445 Project Proposal — Spring 2021

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1. Introduction

• Objective

Car dealers deal with a lot of car keys during working hours, and have a central location where they keep keys to the cars on the lot. Unfortunately, employees sometimes misplace the car keys, forget to return them after using them for test drives, or the car keys could even be stolen. Replacing car keys takes time and money, and also poses a security concern.

To combat all of these issues we are proposing a smarter set of keys and a corresponding key box to house all of these and some of the system's features. The keys would be able to be located by making sounds when looking for them. The key box system would be able to activate, deactivate the keys and give a direction to the key which the user is looking for.

• Background

Car keys now have only a tag on each of them, dealers can know which employee took it and which car it belongs to, but not exactly where it is. When it comes to the case that an employee lost the key, dealers can't do anything with a tag. The same can be said for if the key was stolen. Sure, the dealer could change the keyhole, but it may be stolen with the old key before the keyhole is changed because the thieves steal many keys before actually stealing cars[7], not to mention the time and hundreds of money associated with changing out the locks on the vehicle[8]. With our smart keys and key box, dealers will be able to find the key when it's within some distance away from the key box and be able to deactivate the key when it's too far away from the key box, which will help reduce the probability of a stolen key leading to a lost vehicle.

- ## Visual Aid

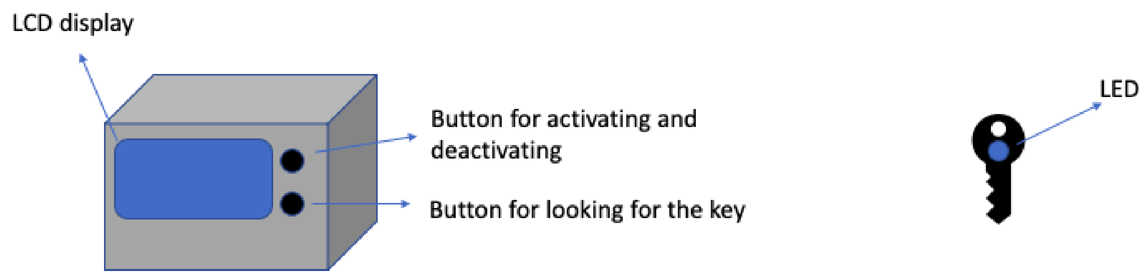

Figure 1. Visual aid for basic settings of the key box and key

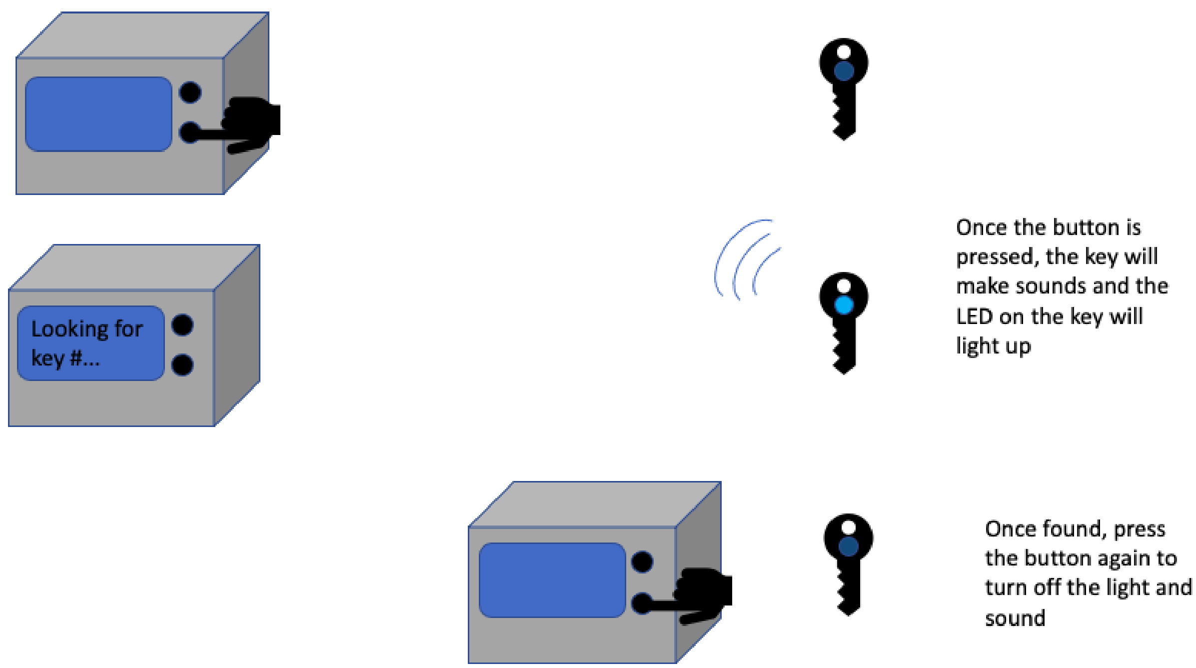

Figure 2. Visual aid for looking for missing keys

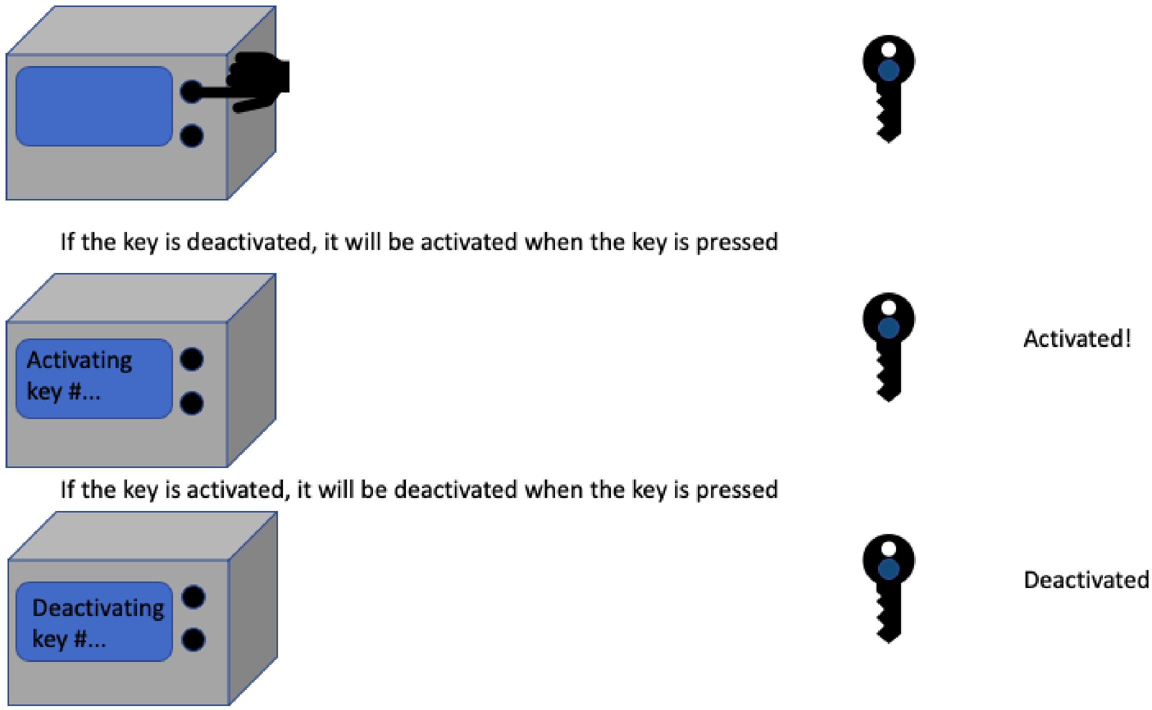

Figure 3. Visual aid for activating/deactivating keys

High-level requirements list

1) Keys that are within 5 meters can be tracked with accuracy over 80% via sound ques for when keys are out of the key box.
2) Keys must be able to be activated and deactivated from 500 meters in case if it were stolen.
3) Key subsection should be within the dimensions of 15 x 7 x 1 cm so that mass storage is convenient and is still easy to fit in pockets like regular keys
4) Box should be locked and display status of keys on LCD screen (accounted for, lost, deactivated, etc)

Functions & Features

1) Locate missing keys within 500 meters
2) LED and speaker indicating location of missing keys
3) Activate and deactivate specified keys
4) Rechargeable battery for the key box
5) Extra protections on circuits of keys

2. Design

The design will be broken down into two different main components. The first will be the component located on the key, and the second being the key box/locator. Within these two components are multiple subsystems. For the key to function, we will have a power supply, feedback module and control module. For the key box to function, we will have a power supply and control module. These subsystems will be explained in more detail in their respective sections.

● Block Diagrams

❖ System overview

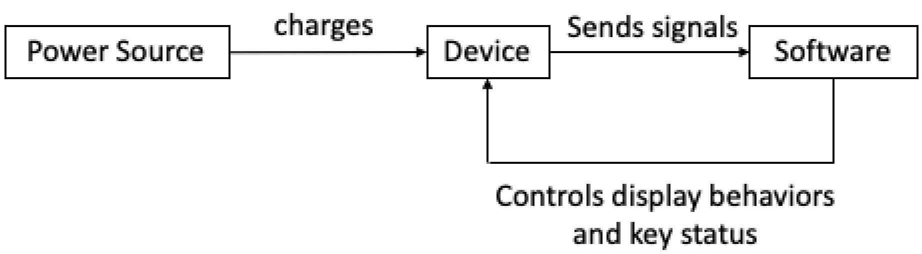

Figure 4. Top-level system block diagram

❖ Device

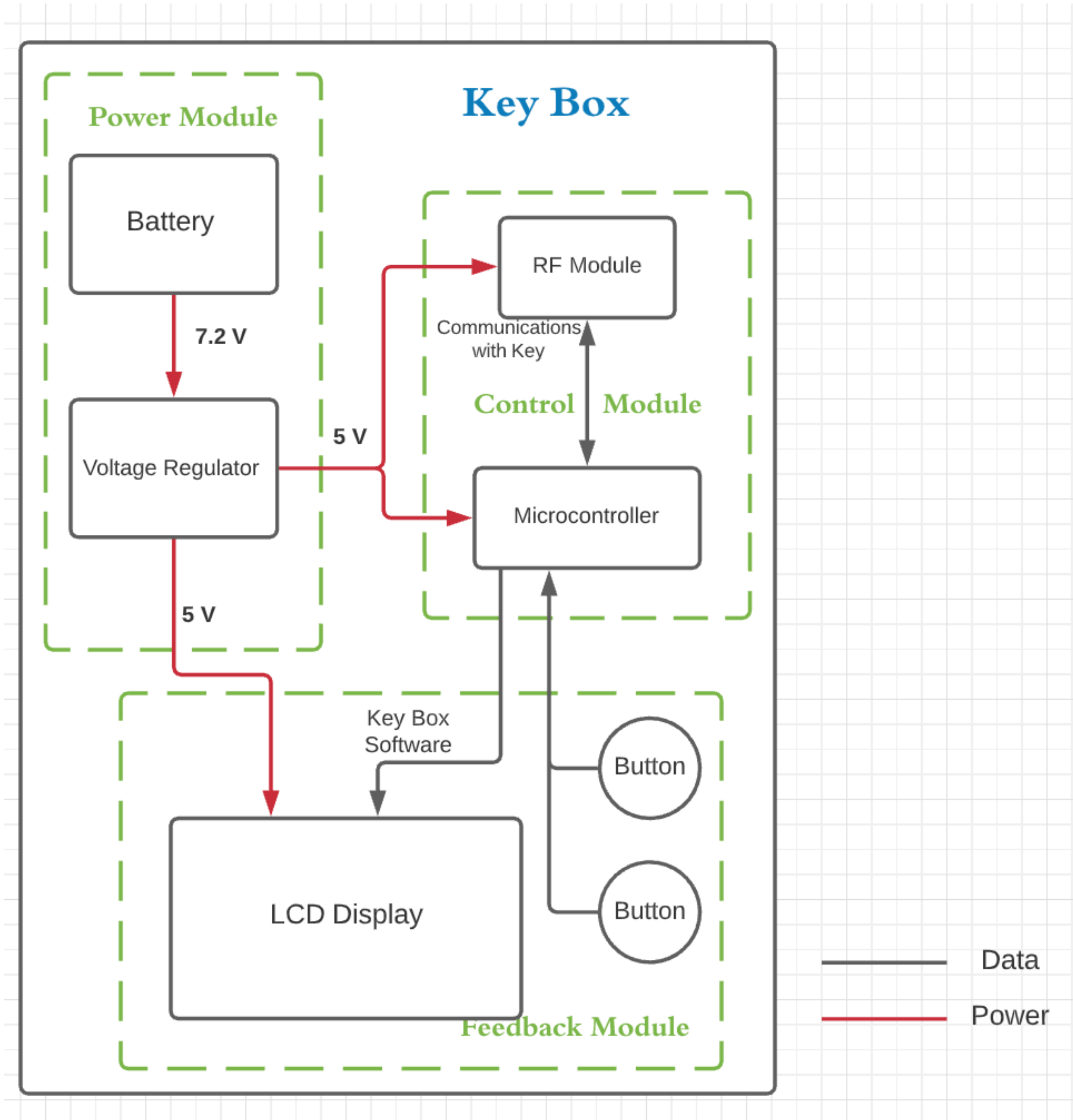

Figure 5.1. Key Box Block Diagram

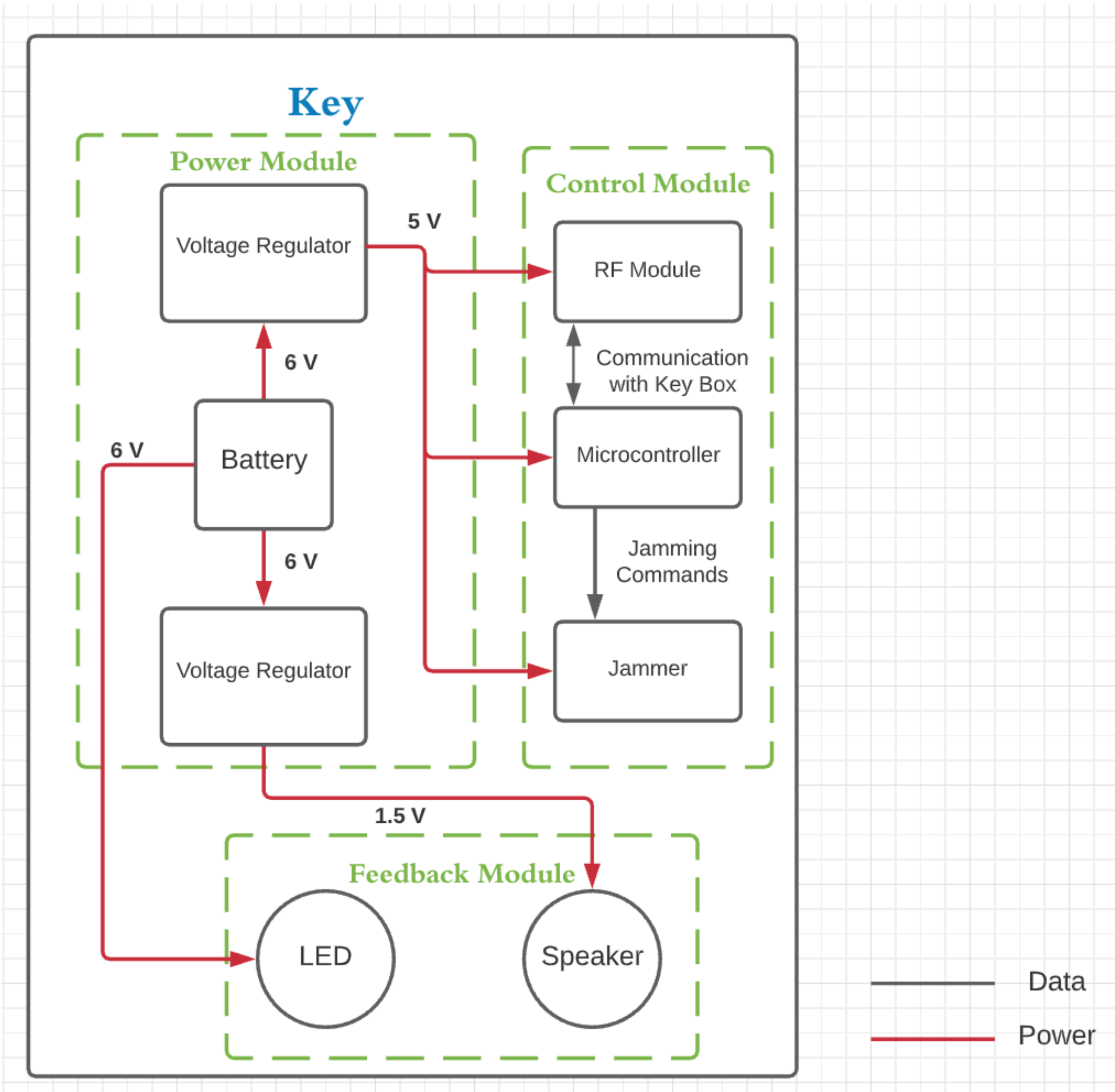

Figure 5.2. Key Block Diagram

❖ Software

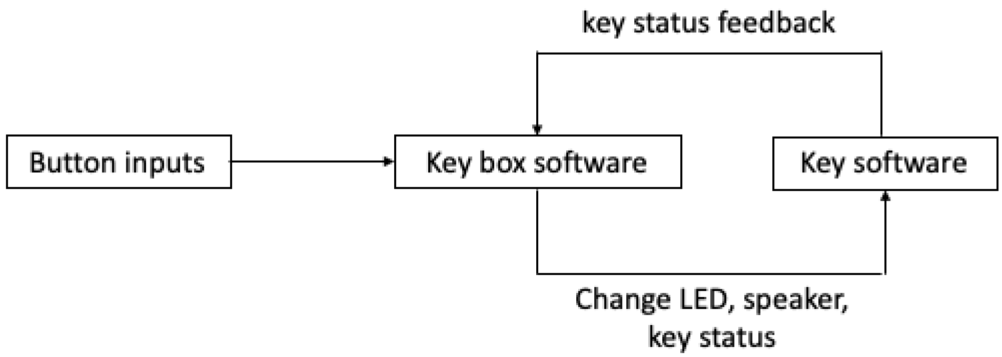

Figure 6. Top-level software block diagram

● Physical Design

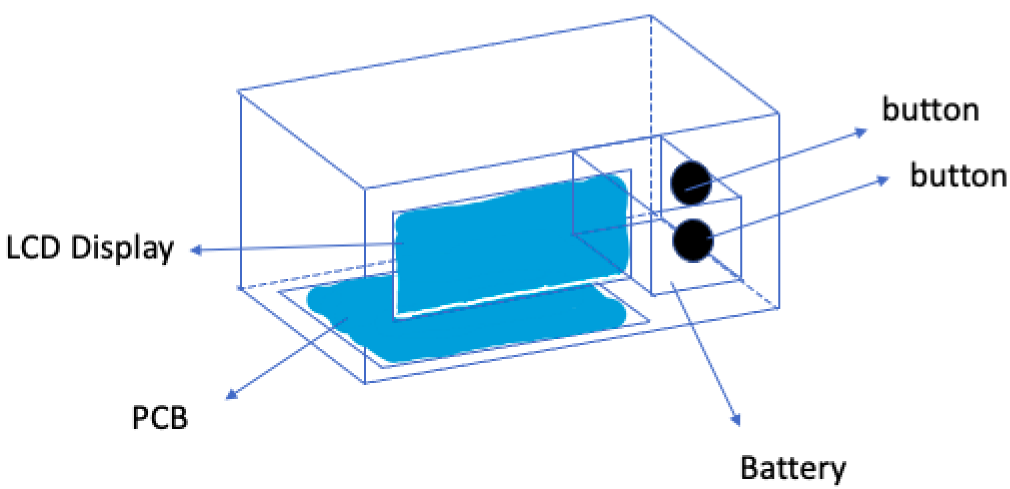

Figure 7. Physical Design of the key box

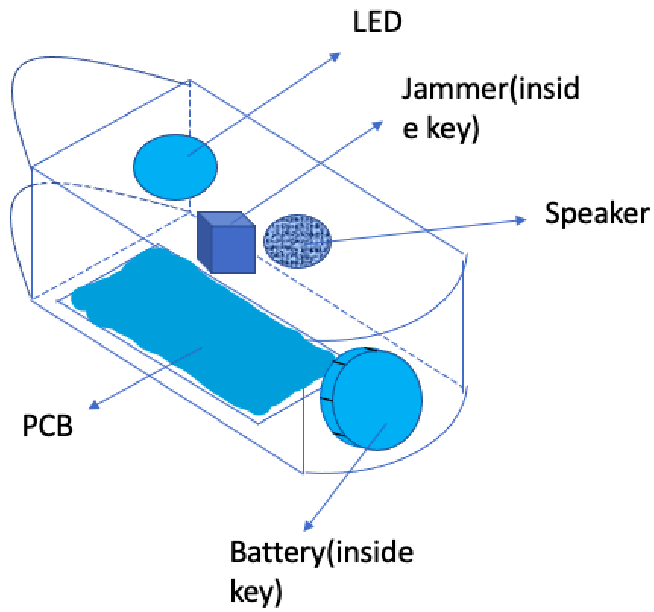

Figure 8. Physical Design of the key

2A Key

The key component of the project will be responsible for making noise and flashing a light to guide users towards it, and must be able to deactivate the functionality of the key if a specific signal is received from the key box.

2A.1 Feedback Module

The communications module will be responsible for guiding the user towards the misplaced key. It will do this by using a speaker and lights that will vary in its behavior depending on signals from the control module.

2A.1.1 Speaker

Input: on/off signal from button
Output: sound

The speaker represents the method for which the user will be able to find the lost device. When the user presses a button on the key box, a signal will be sent out to the respective key, and in turn the speaker will emit a sound. It will receive power via the control module.

Requirements	**Verification**
1. Must be loud enough to be heard from 5 meters away. 2. Must be power efficient due to battery/power constraints (1V~2V)	1. Perform tests within 5 meter radius and ensure it can be easily heard 2. Measure the input voltage and make sure the voltage is within the range of 1V and 2V before connecting to the speaker

2A.1.2 Light (LED)

Input: on/off signal from button
Output: light

The light will also assist in helping the user find the key. It must be bright enough to be seen from a fair distance away (around 5 meters), but also must be power efficient given the power constraints of a small device that also has other features that require power.

Requirements	**Verification**
1. Must be bright enough to be seen from 5 meters away 2. Must be power efficient due to battery/power constraints (6V)	1. Perform tests within 5 meter radius and ensure it can be easily seen 2. Measure the input voltage and make sure the voltage is around 6V before connecting to the LED

2A.2 Control module

This module will be responsible for interpreting signals sent from the key box to determine distance, adjusting the intensity of sound or light being produced by the feedback module, and controlling the jammer to disable the key's functionality.

2A.2.1 RF Module

The RF Module will be the component used to communicate with the key box. It will also determine distance from the key box via its time tracking capabilities, and using that information, send signals to the microcontroller to adjust the frequency of the speaker's audio queues, as well as adjust the blink rate of the LED.

Requirements	**Verification**
1. Must be able to accurately determine distance between itself and key box (accuracy of around 5 meter increments) 2. Must consistently be able to send and receive signals from 500 meters away 3. Must be power efficient due to battery/power constraints (5V)	1. a. Measure sound coming from speaker in decibels from any distance away b. Move towards the speaker (covering at least 5 meters) c. Measure sound coming from speaker again d. Ensure that there is a noticeable change in frequency of audio queues 2. a. Connect RF Module to microcontroller and LED for simple testing circuit b. Set up camera to record circuit to monitor LED c. Send signals from the RF Module on the key box at a distance of 500 meters or less d. Observe camera footage and ensure that the signals were received

2A.2.2 Microcontroller

The microcontroller will adjust the frequency of the speaker's audio queues, as well as adjust the blink rate of the LED based on data received by the RF module. Its final purpose is to control the jammer, which it will do if it has received the corresponding signal from the RF module.

Requirements	**Verification**
1. Must be able to control LED, speaker, and jammer simultaneously 2. Must be power efficient due to	1. Connect LED, speaker and jammer to the microcontroller 2. Activate the jammer 3. Attempt to power speaker and LED

battery/power constraints (5V)	while jammer is active 4. Ensure that all components are working as intended throughout entire duration of test

2A.2.3 Jammer

The jammer will be the device responsible for "deactivating" the key. It will essentially block the operating frequency of the actual car key. This will render the key useless since the car won't be able to receive the key's signals.

Requirements	**Verification**
1. Must not allow any signals to be received by vehicle when jammer is active 2. Must be power efficient due to battery/power constraints (5V)	1. Determine operating frequency of the vehicle whose key is getting jammed 2. Initiate the jammer using the frequency found in 1 3. Attempt to use any function on key 4. Ensure that the car did not receive the key's signals

2A.3 Power Supply

Input: two Lithium 3V non-rechargeable battery
Output: +5V for Microcontroller
+5V for RF module
+1~2V for speaker
+6V for LED

This will be responsible for powering the microcontroller, in turn powering the rest of the components. Because we need 5V for both microcontroller and RF module, we will use 2 watch batteries to power the device due to its small size and long lifetime. We will use two voltage regulators to reduce 6V to 5V, 2V and 2.86V, as below:

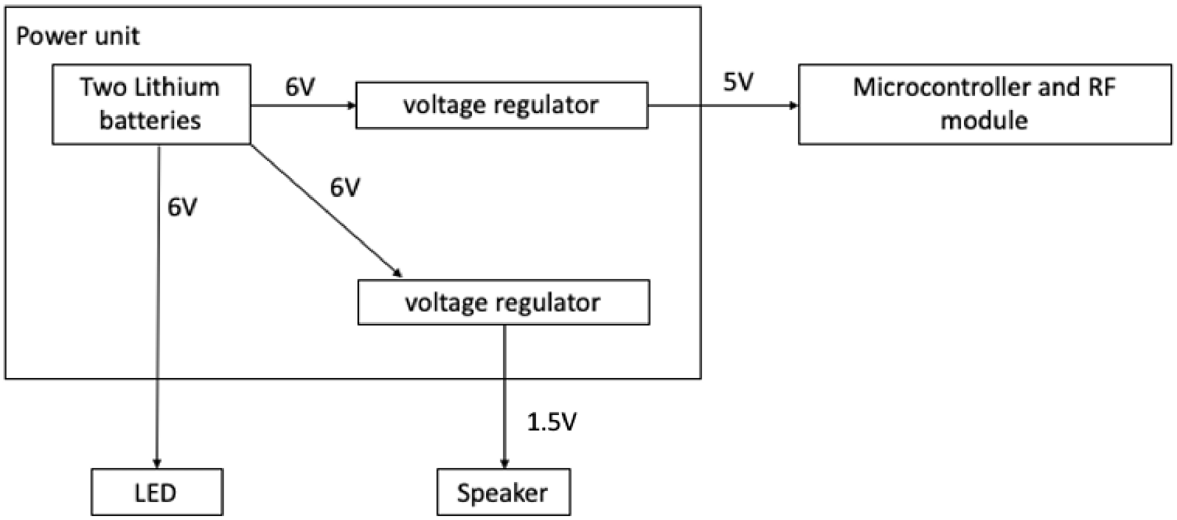

Figure 9. Power supply block diagram for keys

2B Key Box

The key box component of the project will be responsible for tracking the status of all keys (accounted for, missing and active, inactive). It will also be the tool used by the user when searching for lost keys and will be able to remotely deactivate the key via button presses. The statuses for each key will be shown on an LCD display. Since the key box itself requires power and must be mobile, it will be powered by a rechargeable lithium ion battery.

2B.1 Feedback Module

The feedback module will be the main interface used by the user for displaying data from the control module via LCD display, and also provide input data to the control module from the external buttons.

2B.1.1 LCD Display

Input: message signal
Output: messages onto screen

This will be utilized by the microcontroller to update info on the status of keys. The LCD will be able to display the correct messages onto the screen according to the status of keys and the button pressed, as in table 1. The user will be able to check info given by the software running on the microcontroller. Since the device may be used indoors or outdoors, the LCD Display must be bright enough to be easily seen in a variety of environments.

Button pressed	Key status	Message displayed
Upper side button pressed	/	'Looking for key #...'
Lower side button pressed	Activated	'Deactivating key #...'
Lower side button pressed	Deactivated	'Activating key #...'

Table 1. Messages on LCD display

Requirements	**Verification**
1. Must be easily viewed in variety of lighting conditions (eg. Daytime and nighttime) 2. Must display the correct messages listed in Table 1 onto screen 3. Must operate at 5V voltage supply	1. Bring the LCD outside and ensure that the screen is still easily readable. 2. Press different buttons to see if the correct message is displayed. 3. Measure the input voltage and make sure the voltage is around 5V before connecting to the LCD

2B.1.2 Buttons

Input: physical button triggers
Output: digital signal sent to the microcontroller

The buttons on the outside of the key box will function as the way for the user to search for, or deactivate keys.

<u>Button on the upper side:</u>
The button sends the 'looking for missing key' signal to the microcontroller.

<u>Button on the lower side:</u>
The button sends the 'activate/deactivate specified key' signal to the microcontroller

Requirements	**Verification**
1. Must be easy to use, which means the user doesn't need to push very hard to trigger.	1. Measure the input voltage and make sure the voltage is around 5V before connecting to the button

2. Must be able to send out the correct signal stated before this R&V. 3. Must operate at 5V voltage supply 4. Must be debounced	2. Press button 3. Check signal received by the microcontroller to ensure there are no mechanical complications

2B.2 Control Module

The control module will be responsible for incoming data and outputting data to the Feedback Module on the key box as well as all keys. This module will consist of the microcontroller to run software controlling the LCD, and the RF module to communicate with the keys.

2B.2.1 RF Module

The RF Module will be the component used to communicate with the keys and output this data to the microcontroller. This unit will be identical to those used on the keys, so will share the same requirements.

Requirements	**Verification**
1. Must be able to send data back to the key box within 500 meters	1. Key box will receive packets of data containing enough information to carry out appropriate tasks in response

2B.2.2 Microcontroller

The microcontroller will be running software that given input data from the buttons and RF module will update the LED's. Fast processing power is not a high priority in this case since the program does not require the processor to be clocked high, so instead, power consumption is the most important factor since we want to maximize the battery life of the key box.

Requirements	**Verification**
1. Must use about 1W power consumption rate when running software and 0.25W during power save mode. 2. Must successfully estimate the	1. Load software onto microcontroller and monitor power consumption to ensure it meets our standards 2. Carry out Time of Flight calculations for key and update LED's accordingly. The

distance to a key within reasonable margin of error 3. Must be power efficient due to battery/power constraints (5V)	TOF must give a distance reasonably close to the actual distance of the key from the key box.

2B.3 Power Module

This module will include the battery responsible for powering every component in the key box, as well as the components needed to recharge the battery. Additionally, this module will adjust voltages for the microcontroller, RF module, LCD and buttons. Since all of these components require 5 Volts, only one voltage regulator will be necessary.

2B.3.1 Battery

Input: Li-ion 7.2V rechargeable battery
Output: +5V for Microcontroller
+5V for RF module
+5V for LCD display
+5V for buttons

The battery will power all components found in the Control Module and Feedback Module, and must be able to do so for at least 12 hours (the operating hours of most dealerships). Because we need 5 volts for all the parts in key box, we need to reduce 7.2V to 5V as below:

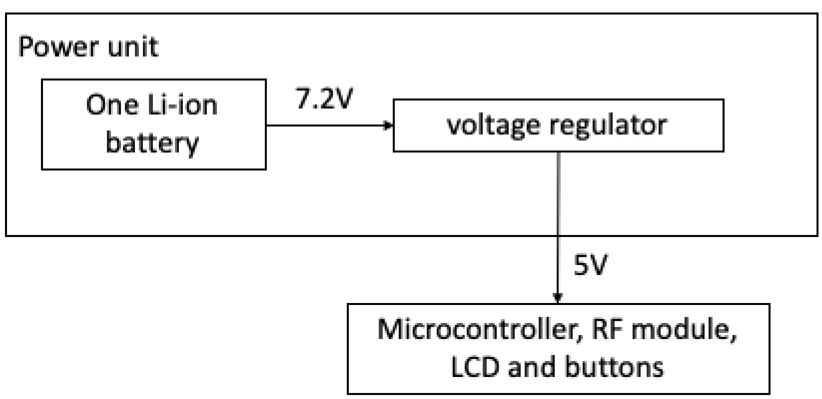

Figure 10. Power supply block diagram for key box

Requirements	Verification
1. Must be able keep at least 90 mAH so that the box can run for the entire 12 hours on one charge.	1. Load software onto microcontroller and monitor power consumption to ensure it meets our standards

2C Software

The software is the high-level controller of the whole system. It receives signals, checks signals, sends signals, displays corresponding messages on the LCD display and monitors the LED and speaker. The overall algorithm is shown below:

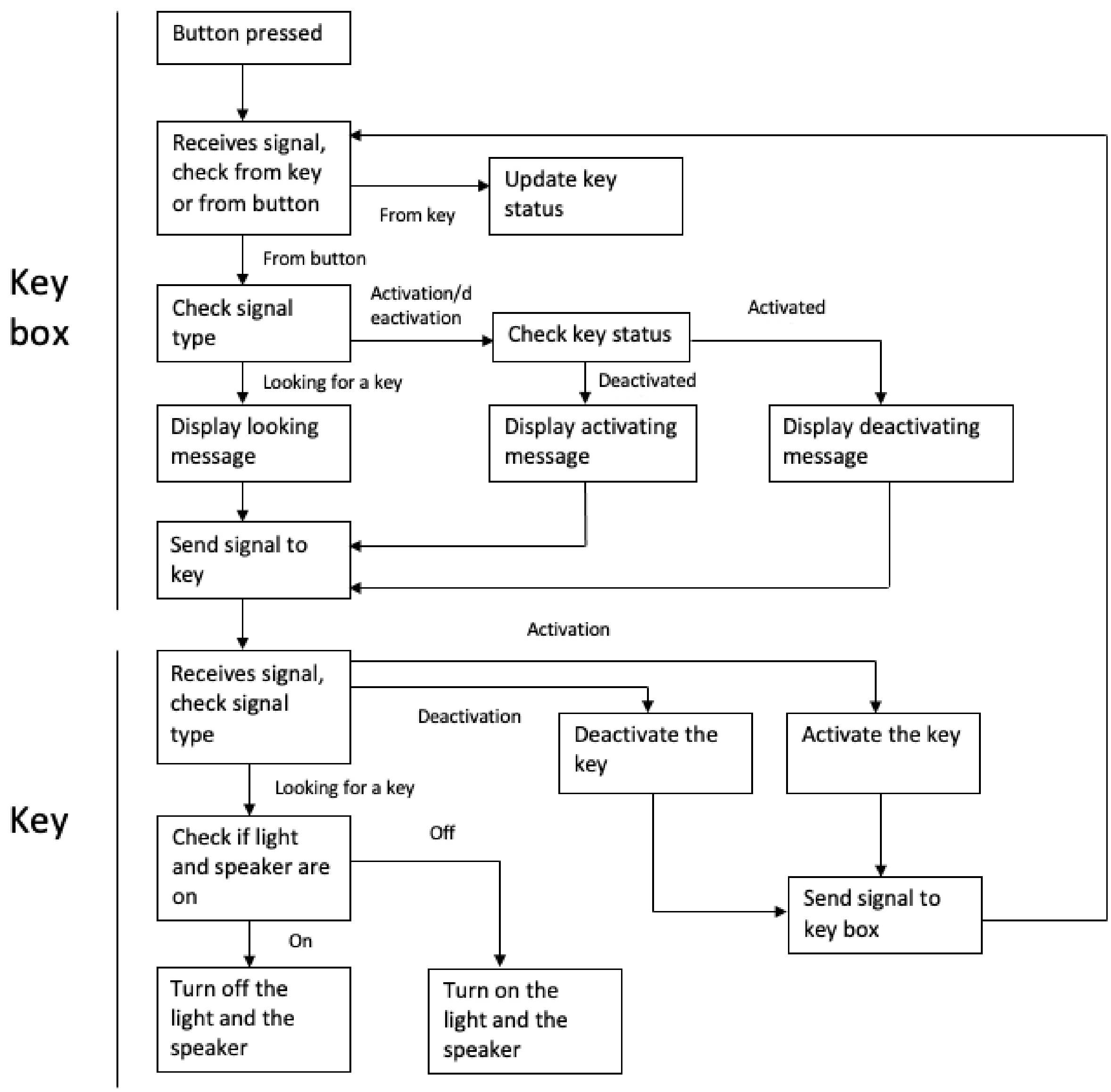

Figure 11. Software algorithm

2D PCB Schematic

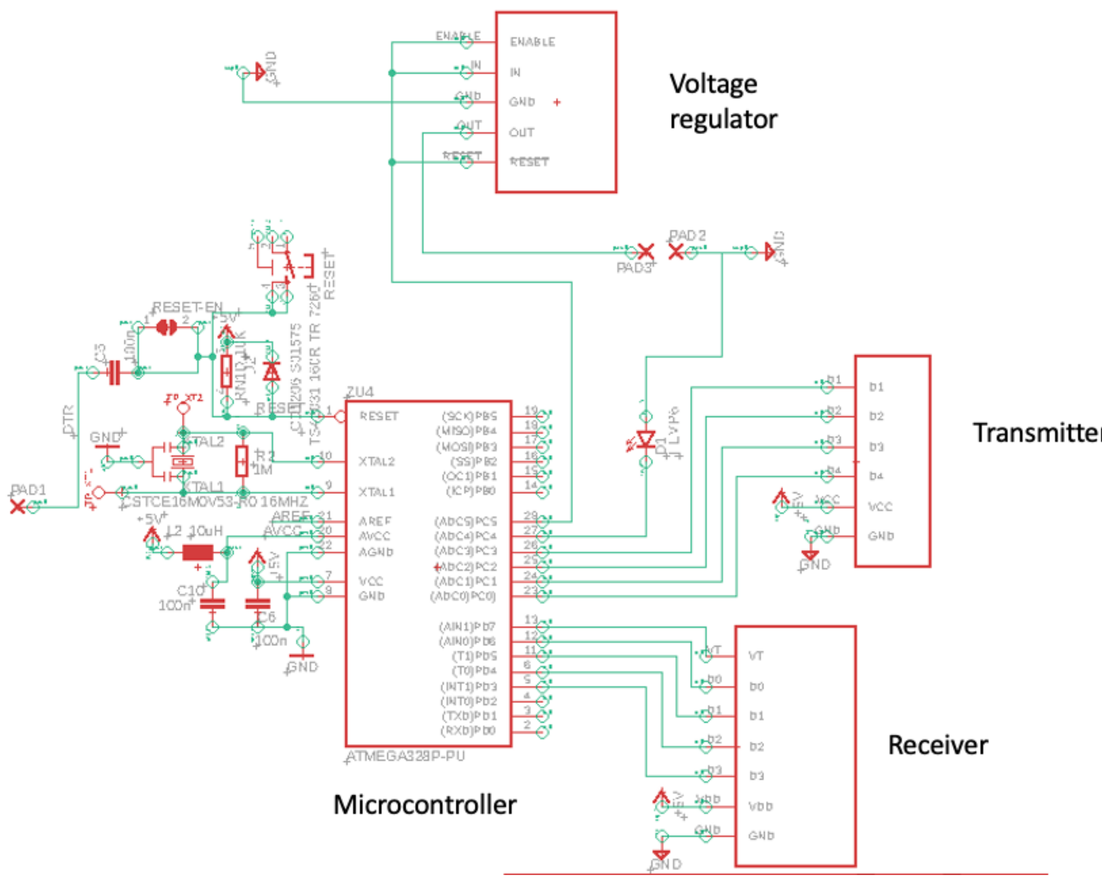

Figure 12. Key schematic

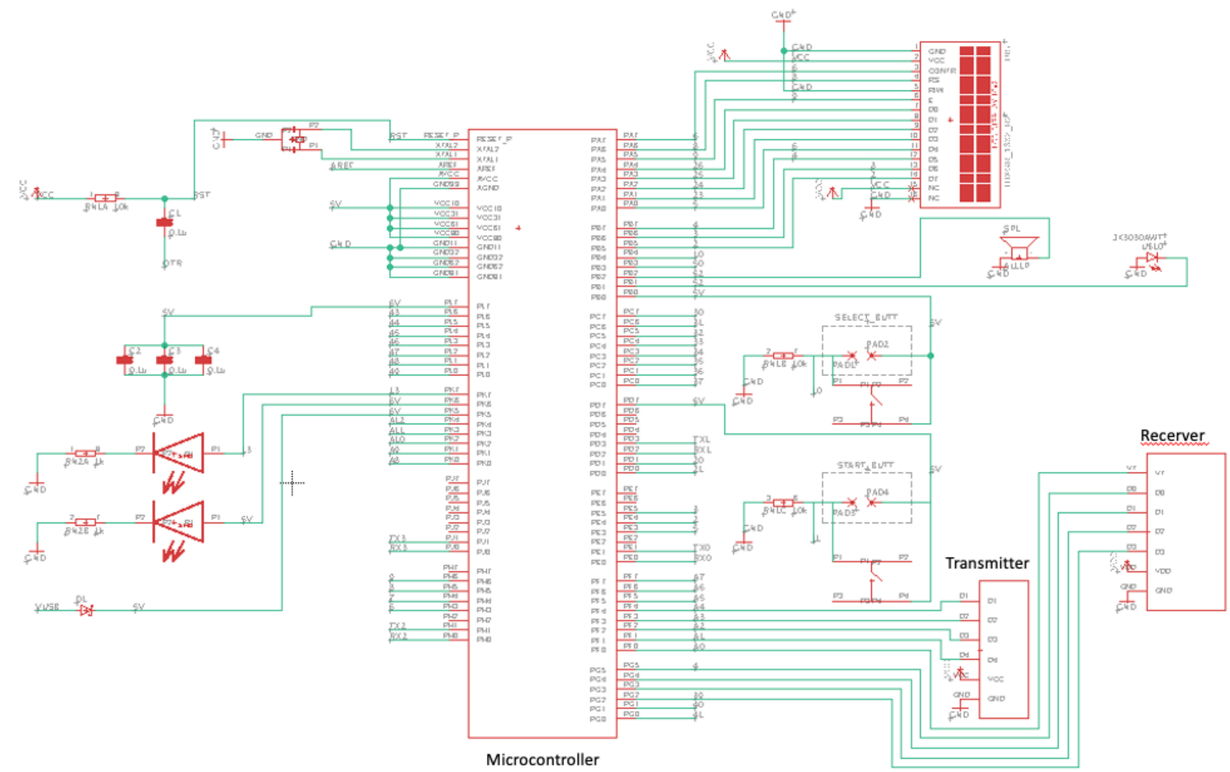

Figure 13. Key box schematic

Tolerance analysis

Our project depends upon the correct tracking of the key by the keybox. For this purpose, we are using the 433MHz transceivers on board each of the key and key box. To achieve this distance measurement. We are calculating distance[3] using the time of flight(TOA) or differential time difference of arrival(DTDOA). This method involves the keybox microcontroller sending a packet to the key which in turn sends its own packet containing internal clock values at time of arrival and time of sending. The microcontroller onboard the keybox will then use this received packet and its own record of sending the packet, to calculate the time elapsed for signal to travel like so[3]:

$$Time\ of\ Flight\ =\ \widehat{t_p}\ =\ (\tau_{B1} - \tau_{A1} + \tau_{A2} - \tau_{B2})/2$$

Where above relationship is defined based on following timing/bounce diagram[3]:

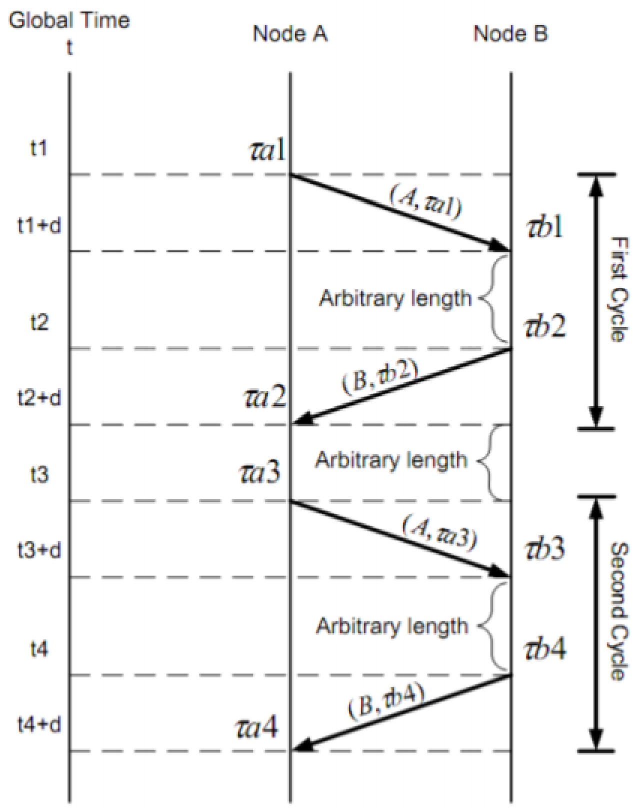

Figure 13. timing/bounce diagram

All the τ'$s$in the above diagram are measures with respect to the local clocks of the CPU. This method does not require the device clocks to be synchronized.
However, there can be extra delay that can cause the distance measurement to be slightly off. These small delays and drift in clock cycles can magnify the error in the domain of speed of light since even 1µs appears as a 300m error in distance[5]. We researched further on the exact nature of the error and the following sources of error have been found in an extensive study[5]:

- Sampling Clock Frequency
  We intend to use a 16MHz oscillator with a rated $\pm$0.5% error. The following model for the error can be found as following

$$\widehat{t_p} = \frac{(t_{B2}-t_{B1})-(t_{A2}-t_{A1})}{2} + \frac{\delta_1+\delta_2}{2} = t_p f_0 + \frac{\delta_1+\delta_2}{2}$$

Equation 1. Sampling clock frequency error

Where the δ’s are the respective errors due to inexact sampling times. The 0.5% does not affect our long distance calculations above 100m but error relative to propagation time for close distance is significant for distances less than that. Also, for higher clock frequencies, we see a much smaller error since the sampling rate also directly varies with propagation delay.

- Clock drift
  The clock drift error can be modeled as follows:

$$\widehat{t_p} - t_p = \frac{1}{4}(\epsilon_A - \epsilon_B)(t_{procB} - t_{procA})$$

Equation 2. Clock drift error

  Where the t_{proc} is the clock drift for the processor of the 2 nodes. We plan to use crystal oscillators which have a typical rating of 20ppm.
- Unequal processing delay

$$\widehat{t_p} - t_p = \frac{1}{4}(\epsilon_A - \epsilon_B)(\Delta_2 - \Delta_1)$$

Equation 3. Unequal processing delay

  This delay(modelled above) may result from different reply times of the processors. In our case, we could keep the process of communication between key and key box as symmetric to account for this error
- Motion of Key
  Even errors due to movement can occur when the target key is mobile during the use of the car. Therefore the following error can be associated with the moving key:

$$\Delta d = \Delta t_{mov} . c$$

Equation 4. Distance of key from key box

  So let us say for $\tau_{b1} - \tau_{a1} = 200ns$, a car going at 70mph can incur $\Delta d = \pm 60m$. Over long distances, this error is minimal but for shorter ranges, this method is very sensitive to error.

Cost and schedule

Cost analysis

- ### Labor

Name	Hourly rate($)	Hours	Total	Total * 2.5
Jacob Connor	50	130	6500	16250
Mehul Kaushik	50	130	6500	16250
Yingtong Hu	50	130	6500	16250

Total	**48750**

Table 2. Labor costs

- ## Parts

Description	Manufacturer	Part #	Quantity	Cost($)
RF module	Seeed Technology Co., Ltd	1597-1225-ND	3	78.99
Microcontroller	Arduino	X000048	1	4.50
Microcontroller	Arduino	ATMEGA2560-16AU	1	13.68
Button	Grayhill Inc.	GH1368-ND	2	4.02
Battery(non rechargeable)	Panasonic - BSG	P138-ND	2	0.76
Battery(rechargeable)	Jauch Quartz	1908-1346-ND	1	28.08
Speaker	Soberton Inc.	433-1104-ND	1	1.73
LED	Cree Inc.	2138-JK3030AWT-P-B50EB0000-N0000001TR-ND - Tape & Reel (TR)	1	0.01
LCD display	Focus LCDs	2632-C162ALBVGSW6WN55PAB-ND	1	8.58
Voltage regulator(for speakers)	Texas Instruments	296-12958-2-ND - Tape & Reel (TR)	1	3.65
Voltage regulator(5V output)	Texas Instruments	296-15015-2-ND - Tape & Reel (TR)	2	1.4
Assortment of resistors, capacitors, oscillators etc.	Digikey(est.)	~	~	8.00

Total	**127.07**

Table 3. Component costs

- Sum of costs into a grand total

Section	Total ($)
Labor	48750
Parts	127.07
Grand total	**48877.07**

Table 4. Grand total costs

2) Schedule

Week	Jacob Connor	Mehul Kaushik	Yingtong Hu
2/8/2021	Come up with project ideas	Come up with project ideas	Come up with project ideas
2/15/2021	Revise the whole proposal	Risk analysis, ethics and safety	Introduction, block diagram, ideas of parts
2/22/2021	Discuss about project design	Discuss about project design	Discuss about project design
3/1/2021	R&V tables, explanation of parts, block diagram, revising introduction	RF module, Microcontroller, Tolerance analysis	Looking for parts, visual aid, physical design, cost and schedule, revising ethics and safety
3/8/2021	Order parts, schematics	Study datasheets for RF module, microcontroller	Study datasheets for all other parts, simulation of circuits
3/15/2021	Test LED, Speaker, LCD and buttons	Program microcontroller	Software development
3/22/2021	Assemble and test power units with other	Test microcontroller, build and test RF	Test software

	parts, build and test RF	module	
3/29/2021	Fix remaining issues, design PCB	Fix remaining issues, design PCB	Fix remaining issues, design PCB
4/5/2021	Fix remaining issues Assemble all components Test PCB	Fix remaining issues Assemble all components Test PCB	Fix remaining issues that can be solved online
4/12/2021	Fix remaining issues Prepare for mock demo	Fix remaining issues Prepare for mock demo	Fix remaining issues Prepare for mock demo
4/19/2021	Make adjustment to the circuits according to TA's feedback Prepare for Demonstration	Make adjustment to the circuits according to TA's feedback Prepare for Demonstration	Prepare for Demonstration Prepare for mock presentation
4/26/2021	Finalize demonstration	Prepare final paper	Prepare presentation
5/3/2021	Finalize final paper	Finalize presentation	Finalize final paper

Table 5. Project schedule and project allocation

3. Discussion of Ethics and Safety

Since our project relies heavily on RF communication with multiple keys. Our project runs the risk of "emitting by products of radio emission" [1]. This would have to control our radio emission in the radio frequencies so as to minimize disruption to other services working close to our device's operating range. We will try our best to remain within the FCC regulations for RF devices as possible[2]. This is most relevant even for our radio jammer to prevent cars from being opened using the keyfob. We do not want to cause interference with nearby RF signals like garage doors, other car doors, emergency alarms etc. one way to curb this is to measure using a receiver if the keyfob is being used and only then apply appropriate jammer frequency at the transmitter to limit interference to surrounding.

According to IEEE code of Ethics[9], We will try our best “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment;”. We will make sure of this by considering the following parts: Battery charging, acceptable sound and light, protection of the circuits and extension of the key.

We will be working with Li ion rechargeable batteries like Li ion. In order to avoid harm to our consumer through shock from uncontrolled voltage/current and prevent overcharging of the batteries, We will do our best to adhere to all safety precautions related to Li ion batteries which may involve double checking our power supply voltages and current, and work within the safe operating points of our chosen battery[2].

On keys, we add speakers and LEDs. For better user experience, we need to make sure that the sound of the speaker is not strident and the light of LED is not dazzling, but they should still maintain the functionality of indicating the place of keys within 5-meters distance from the key box.

Although the key box will be indoor for most of the time, the keys are being carried around and have the possibility of experiencing rain and hit. We need to make sure that water and other damages to the key won’t cause the inside circuit to be shorted, because short circuits bring danger to the user[6]. To deal with this problem, we will add extra protection onto the circuit inside the key. The LED and the speaker will be the connection of outside and inside of keys, so we also need to make sure that water won’t go inside the key from these two places by adding additional protection.

Consumer safety may also extend to moving parts in our project: for example, the actuator that deactivates physical keys by lodging a piece of metal in the key that prevents it from fitting in the keyhole. One way to prevent harm to user of key in case the actuator is triggered, is to carefully control torque such that it has sufficient strength to block the key from usage but at the same time, it is slow enough and comes with a warning through sound so as to alert user of the deactivation process. The slower motor will be less of a mechanical hazard since it gives the user time to move out of its way though in future design, we will continue to work on this challenge keeping user safety and security in mind.

When we are working in lab, we will be working with all the electronic parts and may need to weld the circuit. And we will be working in the same lab with other people, which is a safety risk during Covid time. To prevent possible harm to us, we will attend lab safety training, follow the instructions and be careful during work.

4. Citations

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