Smart Keys/Key box

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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, not to mention the time and money associated with changing out the locks on the vehicle. 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

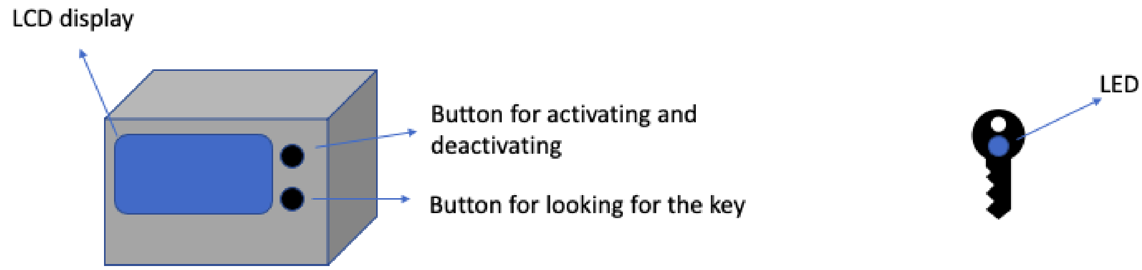


Figure 1. Visual aid for basic settings of the key box and key

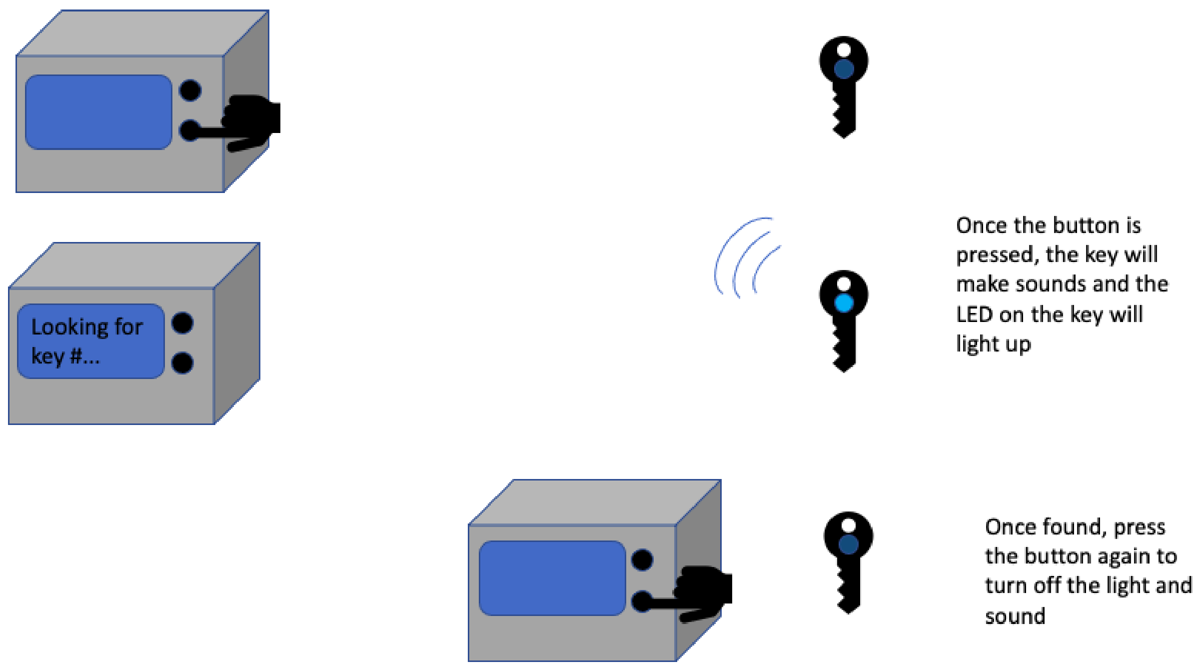


Figure 2. Visual aid for looking for missing keys

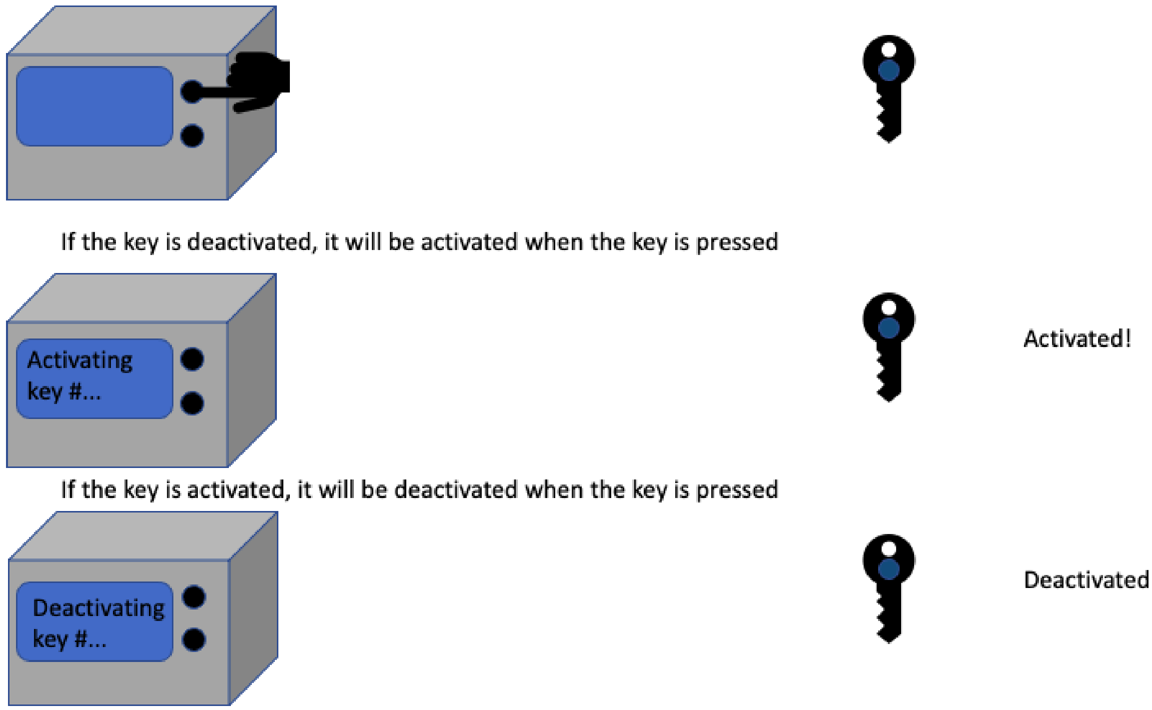


Figure 3. Visual aid for activating/deactivating keys

- ### High-level requirements list

  1) Keys that are within specific distance can be tracked easily and effectively via sound ques for when keys are misplaced
  2) Keys must be able to be deactivated from long distances in case if it were stolen
  3) Key subsection should be compact so that mass storage is convenient and is still easy to fit in pockets like regular keys
  4) Box should be secure and display status of keys (accounted for, lost, deactivated, etc)

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 Diagram

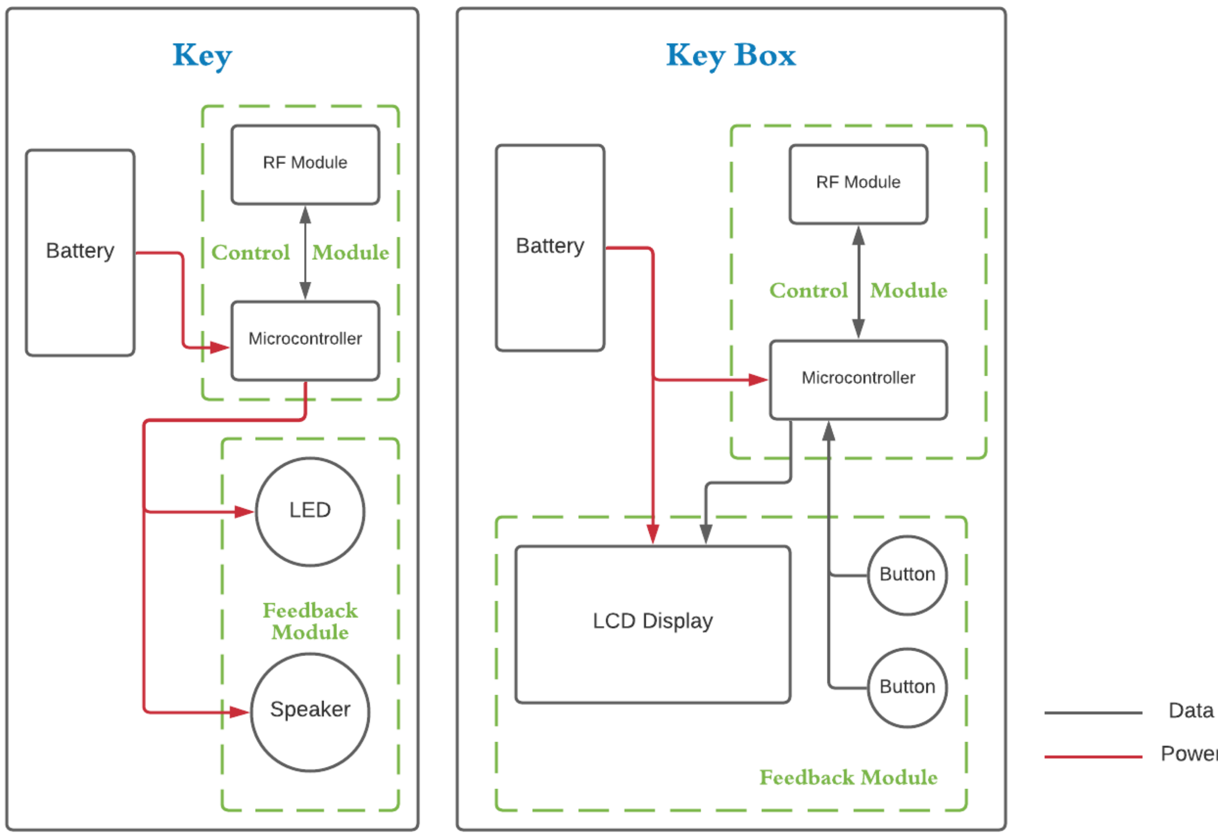


Figure 3. Block Diagram

- ## Physical Design

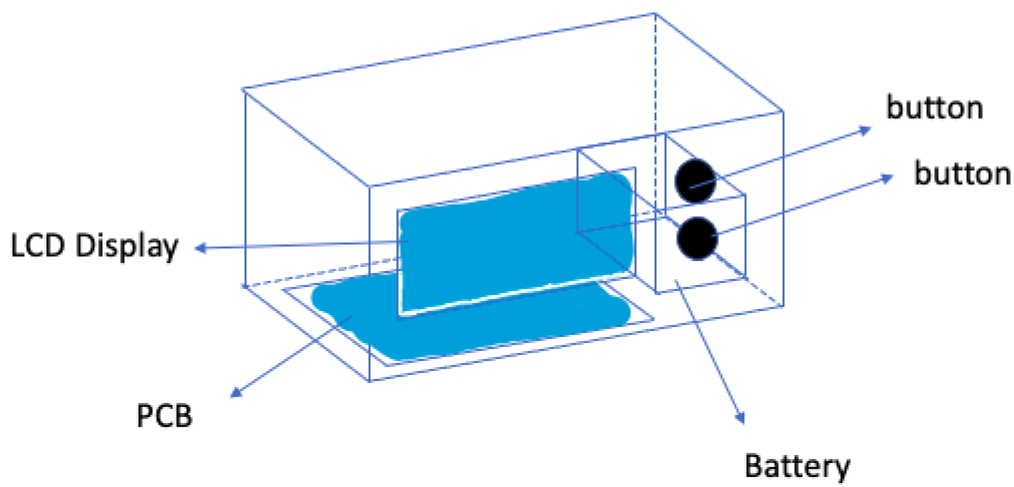


Figure 4. Physical Design of the key box

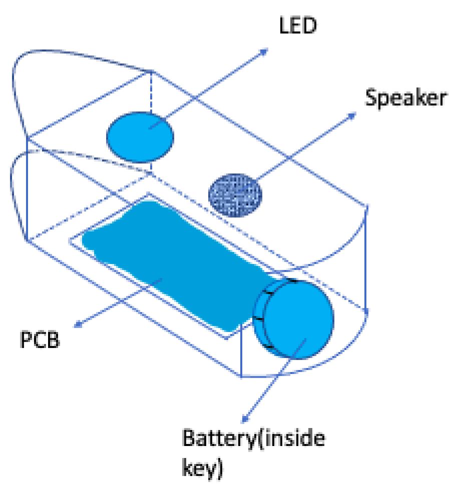


Figure 5. Physical Design of the key

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

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 (decide this distance before submitting) 2. Must be power efficient due to battery/power constraints	1. Perform tests within 5 meter radius and ensure it can be easily heard

2A.1.2 Light (LED)

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	1. Perform tests within 5 meter radius and ensure it can be easily seen

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 y meter increments) 2. Must consistently be able to send and receive signals from 5 meters away	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 5 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	3. a. Connect LED, speaker and jammer to the microcontroller b. Activate the jammer c. Attempt to power speaker and LED

	while jammer is active d. Ensure that all components are working as intended throughout entire duration of test

2A.3 Power Supply

This will be responsible for powering the microcontroller, in turn powering the rest of the components. We will use a watch battery (possibly 2 if parts picked demand more voltage) to power the device due its small size and long lifetime.

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

This will be utilized by the microcontroller to update info on the status of keys. 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.

Requirements	Verification
1. Must be easily viewed in variety of lighting conditions	1. Bring the LCD outside and ensure that the screen is still easily readable.

2B.1.2 Buttons

The buttons on the outside of the key box will function as the way for the user to search for, or deactivate keys. There will also be a button to disable the LCD screen to greatly conserve battery life when the box isn't being actively used.

Requirements	**Verification**
1. Must be easy to use	1. Press button and 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	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 distance to a key within reasonable margin of error	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 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.

2B.3.1 Battery

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).

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.	3. Load software onto microcontroller and monitor power consumption to ensure it meets our standards

2B.3 Software

- The software receives signals, sends signals, displays corresponding messages on the LCD display and monitors the LED and speaker. The overall algorithm is shown below:

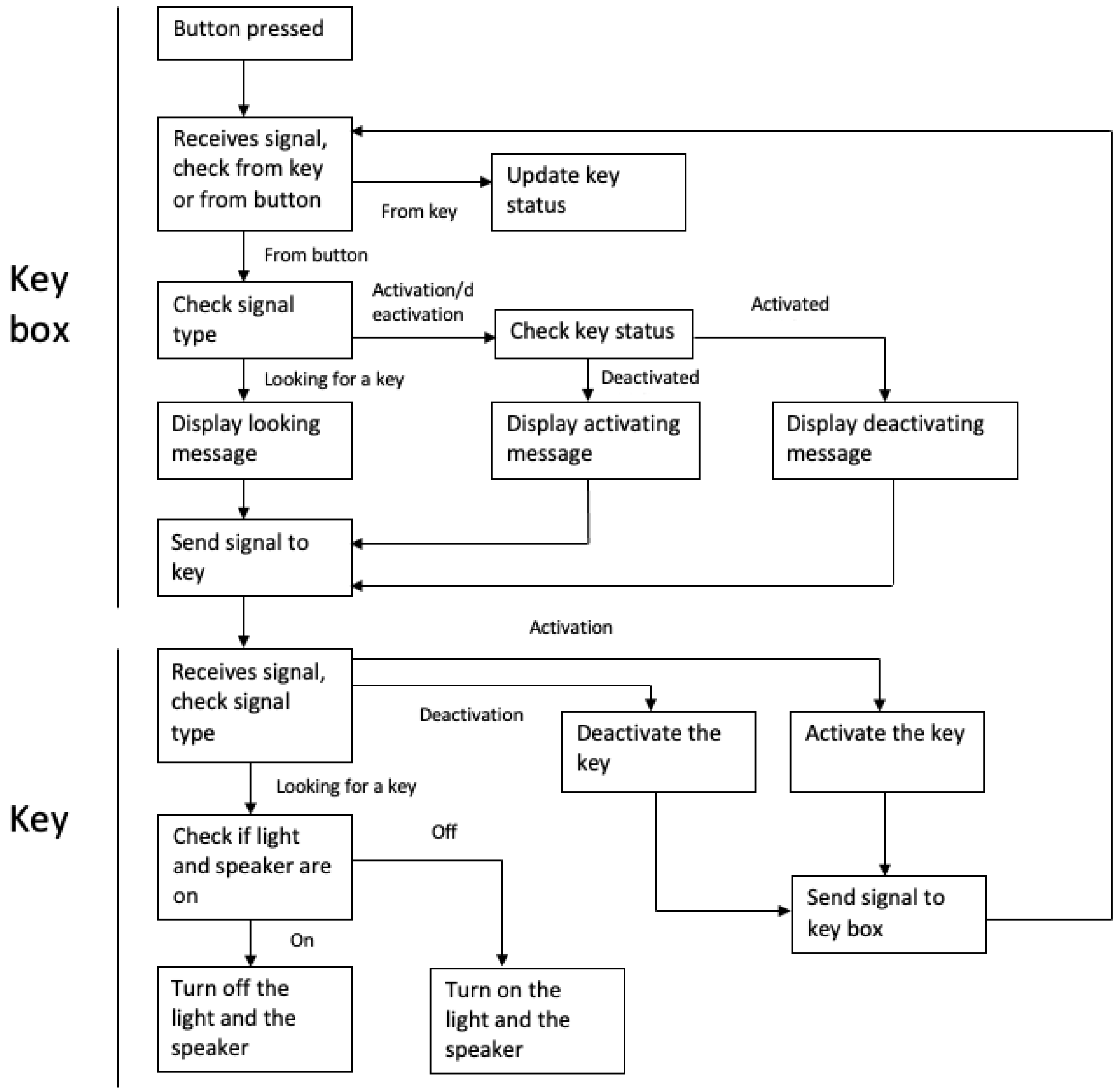


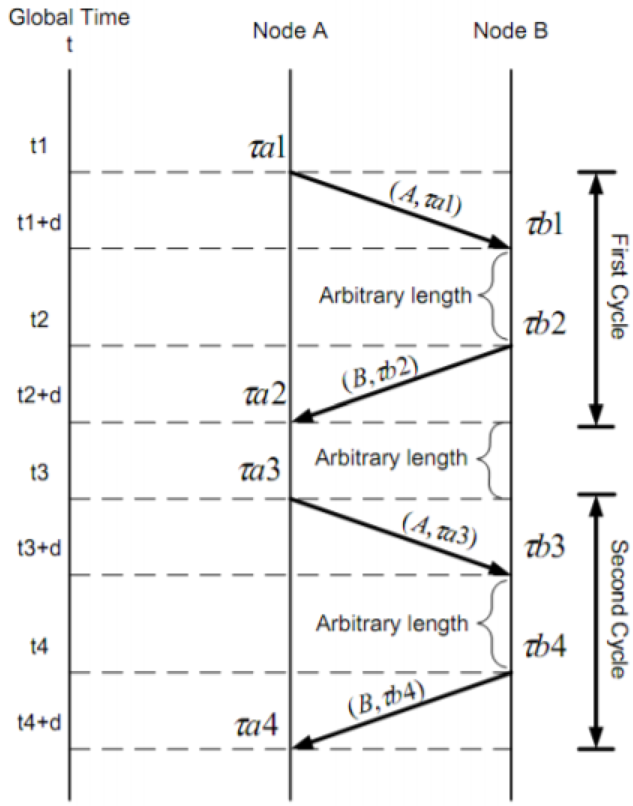
Figure 6. Software algorithm

• 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]:



All the $\tau's$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 ±0.5% error. The following model for the error can be found as following
  $$\widehat{t_p} = \frac{(t_{B2}-t_{B1})-(t_{A2}-t_{A1})}{2} + \frac{\delta_1+\delta_2}{2} = t_p f_0 + \frac{\delta_1+\delta_2}{2}$$
  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:

  $$\hat{t}_p - t_p = \frac{1}{4}(e_A - e_B)(t_{procB} - t_{procA})$$

  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

  $$\hat{t}_p - t_p = \frac{1}{4}(e_A - e_B)(\Delta_2 - \Delta_1)$$

  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:

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

  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.

3. Cost and schedule

1) Cost analysis

- Labor(For each partner in the project)

  50$/hour * 2.5 * 3 * 10hours/week * 9 weeks = 33750$

- Parts

Description	Manufacturer	Part #	Quantity	Cost($)
RF module	Seeed Technology Co., Ltd	1597-1225-ND	2	52.66

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)	GlobTek, Inc.	1939-2037-ND	1	17.02
Speaker	Soberton Inc.	433-1104-ND	1	1.73
LED	Samsung Semiconductor, Inc.	1510-SPHBL1L3DH00L4A4B0TR-ND - Tape & Reel (TR)	1	0.93
LCD display	Focus LCDs	2632-C162ALBVGSW6WN55PAB-ND	1	8.58
Assortment of resistors, capacitors, oscillators etc.	Digikey(est.)	~	~	8.00

- Sum of costs into a grand total

  33750 + 8.58 + 4.02 + 0.76 + 17.02 + 1.73 + 0.93 + 52.66 + 4.5 + 13.68 + 8 = 33861.88$

2) Schedule

Week	Goal	Main responsible team member
March 7	1. Buy & Test parts 2. Design distance-detect	1. Jacob 2. Mehul & Yingtong

	beeper	
March 14	1. Assemble & Test distance-detect beeper 2. Design inner switch and signal receiver	1. Jacob 2. Mehul & Yingtong
March 21	1. Assemble & Test inner switch and signal receiver 2. Design control module	1. Jacob 2. Mehul & Yingtong
March 28	1. Assemble & Test control module 2. Adjust design according to test result	1. Jacob & Mehul 2. All team members
April 4	Adjust design for each part according to test result	All team members
April 11	1. Integrate and test whole system 2. Adjust design according to test result	1. Jacob & Mehul 2. All team members
April 18	1. Mock demo 2. Adjust design according to feedback from mock demo	All team members
April 25	1. Demo 2. Final paper	1. Jacob & Mehul 2. All team members

May 2	Final paper	All team members

4. 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 car 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.

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. 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.

5. Citations

[1] "Equipment Authorization – RF Device." Federal Communications Commission, 20 Mar. 2018, www.fcc.gov/oet/ea/rfdevice.

[2] Reczek, Karen, and Lisa M Benson. "A Guide to United States Electrical and Electronic Equipment Compliance Requirements." 2017, doi:10.6028/nist.ir.8118r1.

[3] Garcia, Saul Emmanuel, Brian Shaw, and Ryan Joseph Dobbins. Software Defined Radio Localization Using 802.11-style Communications. : Worcester Polytechnic Institute, 2011.

[4] Chaudhari, Qasim. "There and Back Again: Time of Flight Ranging between Two Wireless Nodes." DSP, 23 Oct. 2017, www.dsprelated.com/showarticle/1100.php.

[5] Baba, Asif Iqbal. "Calibrating Time of Flight in Two Way Ranging." 2011 Seventh International Conference on Mobile Ad-Hoc and Sensor Networks, 2011, doi:10.1109/msn.2011.23.