# HABIT FORMING KEY STATION

**Team 17**

**Cedric Mathew (cmathe26)**

**Ali Husain (alijh2)**

**Marsh Ma (yuxuanm4)**

**Professor: Arne Fliflet**

**TA: Abhisheka Mathur Seka**

**23 February 2024**

# Contents

# 1. Introduction

## 1.1 Problem

People have a difficult time building good habits. A common issue that many people encounter is losing or misplacing their keys whenever they enter their home. People often leave their keys in random places around the house, leaving them scrambling to find them when it's time to leave. If they were accustomed to placing and grabbing their keys from a specific designated location, then the likelihood of losing their keys and wallet would be significantly low.

## 1.2 Solution

Our solution is the habit-forming key dish: a designated home for your valuable keys that trains you to keep them in the right place every time. This key dish utilizes negative reinforcement to build positive habits for its users. The key dish will be equipped with a pressure sensor, RF tracking, a speaker, and a snooze button. We utilize RF tracking to detect when the user has come home but hasn't put their keys in the dish. At this moment, we will sound an alarm on the speaker, notifying the user that they need to place their keys into the dish. The user can either place the keys into the dish or press the snooze button to turn off the alarm. This solution forces users to always keep their keys in their designated spot and prevents them from losing them in their home ever again.

## 1.3 Visual Aid

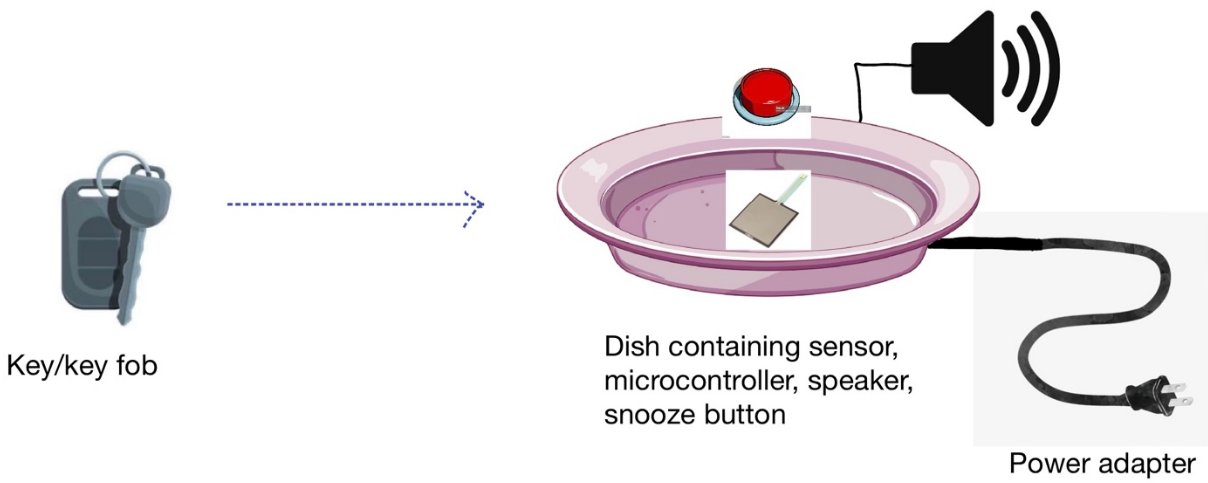


Figure 1: Visual aid of our solution

## 1.4 High Level Requirements

- The microcontroller waits 2 - 4 minutes after removing the keys from the pressure plate before enabling the proximity subsystem to detect the keys
- The proximity subsystem should detect the key fob at a minimum of 15 feet from the dish. Upon detecting the keys, it should wait 30-90 seconds before sounding the alarm.
- The alarm turns off by either placing the keys in the dish or pressing the snooze button within 5 seconds of either method

# 2 Design

## 2.1 Physical Design

The following image describes how our dish will look like. At the base of the dish is a square pressure sensor which is where the user should place their keys. The snooze button is not pictured in this visual aid but will be somewhere on the side of the bowl. Also, a special key fob will be attached to the keys which communicate with our dish.

Figure 2: Physical diagram of our solution

## 2.2 Block Diagram

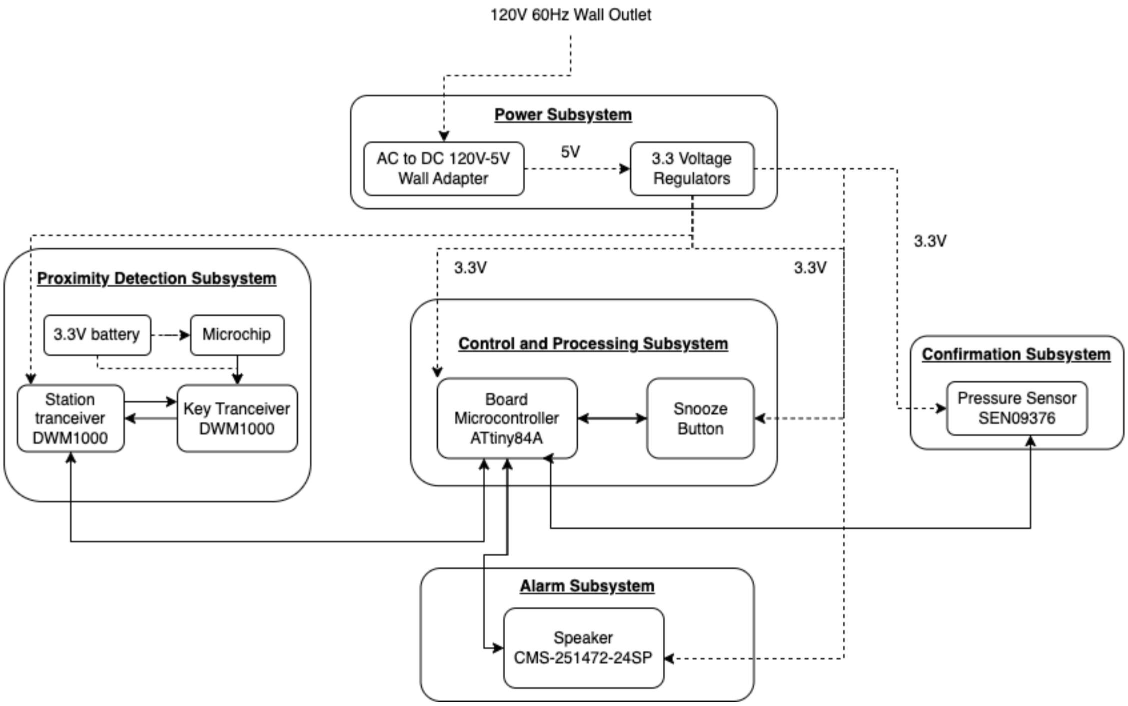


Figure 3: Block diagram outlining subsystem connection

The project's design integrates several critical subsystems to promote habitual key placement. The Proximity Detection Subsystem is the first point of user interaction, utilizing an RFID reader to detect keys equipped with a corresponding tag. Following detection, the Control and Processing Subsystem, centered around an ATtiny84A microcontroller, evaluates the presence of the keys and commands the Alarm Subsystem if the keys are not placed in the designated area, activating a Piezo Buzzer to alert the user. The Confirmation Subsystem, equipped with a pressure sensor, confirms the placement of the keys, deactivating the alarm. Lastly, the Power Subsystem ensures the seamless operation of all components by supplying consistent electrical power derived from a standard outlet.

## 2.3 Subsystems Overview

### 2.3.1 Power

The Power Subsystem serves as the backbone of the habit-forming key station, providing the necessary electrical power to all other subsystems. Central to this system is a power adapter capable of delivering a wide range of output voltages from 5.0V to 36.0V [1], adaptable to meet the different requirements of the project's components. For this design, the adapter is set to deliver a 5V output, chosen for its compatibility with the voltage regulator that follows. A key component of the Power Subsystem is the high-efficiency voltage regulator, tasked with converting the 5V input from the adapter to the lower voltages required by the project's components [2]. This regulator is crucial for stepping down the 5V to 3.3V, a common operating voltage for many of the subsystems' components, including sensors and microcontrollers. The efficiency of this regulator is paramount, as it directly impacts the overall energy consumption and thermal performance of the system. Assuming an efficiency rate of over 90%, the regulator ensures minimal energy loss during conversion, optimizing the system's power usage and prolonging the lifespan of the components through reduced heat generation. The design considerations for the Power Subsystem extend to the total power capacity and distribution. The adapter can provide up to around 10.5 Watts, and that is more than enough, surpassing our need of around 2.75 Watts. With the power adapter capable of supplying up to 2.10A at 5V, the system can handle the cumulative current draw of all connected subsystems, ensuring stable operation even under peak loads. This capacity is essential for maintaining uninterrupted functionality across the Control and Processing, Proximity Detection, and Alarm subsystems, among others, providing a reliable power source that can adapt to varying demands.

| Requirements | Verifications |
| --- | --- |
| **Provide a stable 5V output under load.** | • Conduct load testing with a multimeter |

| | |
|---|---|
| | • Ensure voltage remains within 5% of 5V. |
| **Support total current draw of 500mA without overheating** | • Execute a continuous operation test.<br>• Monitor temperature to stay within safe limits |
| **Voltage regulators must be able to output 3.3 VDC +/- 0.1 V with at most 1A of current** | • Connect adapter to voltage regulators<br>• Connect test load resistors<br>• Confirm voltages at differing current values<br>• Confirm results are in range of 3.3V +/- 0.1V |

### 2.3.2 Alarm

The Alarm Subsystem within our habit-forming key station project is built around the CMS-251472-24SP speaker, chosen for its acoustic performance and compatibility with the system's power output low [3]. This speaker, operating at an optimal voltage of 2.83V, is particularly well-suited for small, portable electronic devices where power efficiency is important. The speaker's specifications, including a rated power of 2W and an impedance of 4 ohms, were critical factors in its selection. These parameters indicate the speaker's ability to produce a robust sound output while maintaining energy efficiency. The rated power ensures that the speaker can emit a sound loud enough to be clearly heard across typical household environments, a necessity for the alarm function to effectively remind users to place their keys in the designated spot. An important feature of the CMS-251472-24SP is its sound pressure level (SPL) of 80-83 dB at 1W/0.5m, which ensures the alarm is audible at a distance, even in potentially noisy environments. This SPL range is chosen to have a balance between ensuring the alarm is noticeable and avoiding excessively loud sounds that could be startling. The speaker's frequency response is also a key consideration, allowing for flexibility in designing alarm tones that are distinct and easily recognizable, avoiding confusion with other household sounds. The mechanical design aspects, such as the speaker's mounting and positioning within the key station, are planned to optimize sound propagation and minimize obstructions. This ensures that the alarm's sound is directed outward and distributed evenly throughout the environment, maximizing its effectiveness. To enhance the Alarm Subsystem, we included a snooze feature, enabling users to delay the alarm signal for a set period to allow the user to choose not to place it down if they do not need to. Lastly, the speaker's output reaches 80 dB within the critical frequency band where human hearing is most sensitive, around 2.5 kHz to 4 kHz, ensuring the alarm's signal is not only clear and audible but also efficiently cuts through ambient noise. This peak in the frequency response curve is leveraged in the design to maximize the alarm's effectiveness without increasing power consumption, in line with the system's energy efficiency goals.

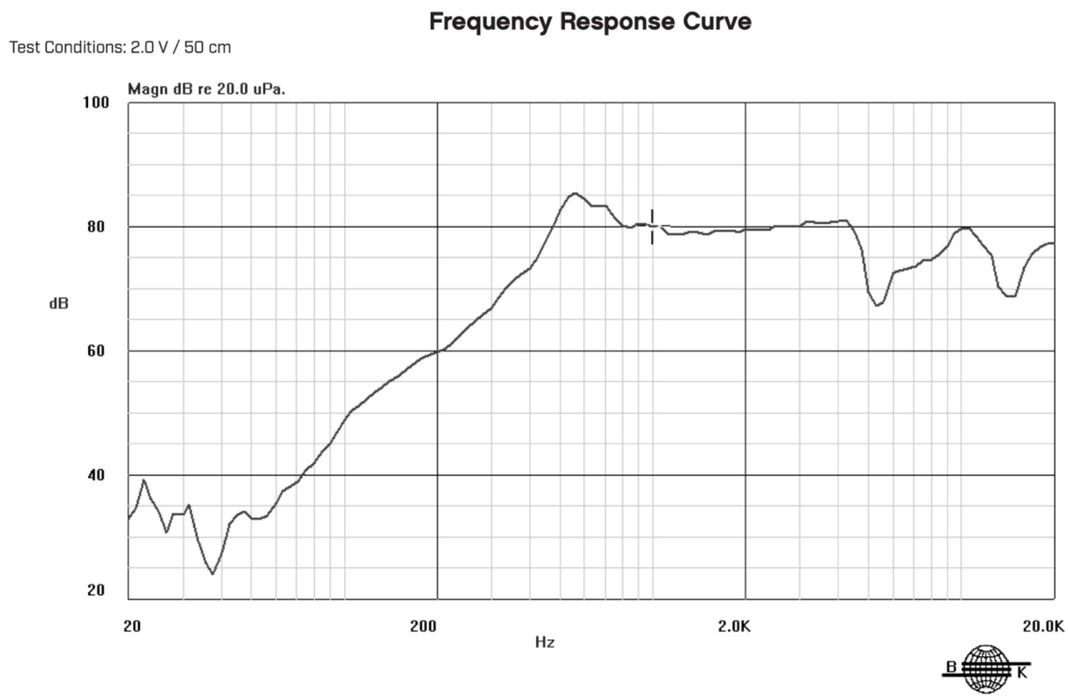


Figure 4: Speaker's response (dB) to different frequencies (Hz)

| Requirements | Verifications |
|---|---|
| **The alarm must be audible at 80 dB SPL at 1 meter.** | • Test with a sound level meter at 1 meter.<br>• Confirm SPL meets/exceeds 80 dB |
| **Speaker power consumption should not exceed 2W.** | • Measure power usage with a multimeter.<br>• Connect load to test voltage at differing current levels<br>• Ensure it is within 2W during operation |
| **Alarm tones must be within the human audible range.** | • Perform audio frequency analysis<br>• Verify output is within 500 Hz to 4 kHz |
| **Accurate timing for the snooze duration before re-activating the alarm** | • Measure the interval between snooze activation and alarm re-activation |

### 2.3.3 Control and Processing

The control subsystem is responsible for maintaining the state of the key dish device. It is the brains of the operation and is connected to every other subsystem. Our device has four states: sleep, timer, waiting, and alarm.

The dish starts in the sleep state, where it detects the keys inside it. This will be accomplished through the confirmation subsystem that can sense the weight of the keys at the base of the dish. When the keys are removed from the dish, our system will enter the timer state. It will wait a minimum of 2 minutes before it begins detecting the proximity of the keys. This timer state is necessary as we don't want the system to enter an alarm state as soon as the keys are removed from the dish and the user hasn't left their home yet. Upon entering the waiting state, it will wait until the keys have entered the designated proximity radius. If the keys are within the designated proximity radius for at least 30 seconds, it will enter the alarm state. If the keys are placed in the dish, as indicated by the pressure sensor, the dish will enter the sleep state. If the user wants to turn the alarm off without keeping their keys in the dish, they can press the snooze button, which will bring the system back to the timer state. A state diagram in figure X below shows how the device transitions between states.

The control subsystem contains the ATtiny84a microcontroller and snooze button. This microcontroller is relatively lightweight with 12 general purpose I/O lines, 8 KB ISP Flash memory, 512B EEPROM, and 512B SRAM. The control subsystem will receive 3.3V from the power subsystem [5]. We can keep the microcontroller perpetually running as we will always have access to power. The speaker subsystem will be fed a simple square wave when in the alarm state, as determined and provided by the control subsystem. The proximity subsystem will communicate with the microcontroller over SPI. It utilizes the DWM1000's time of flight metric to measure how far the keys are from the dish and modify the internal state accordingly. It will also be connected to the confirmation subsystem, which will feed a voltage to the microcontroller. Upon testing, we will know how specific voltages correspond to different weights upon the pressure sensor, and can change state accordingly. Upon pressing the snooze button, if and only if the system is in the alarm state, it will transfer to the sleep state.

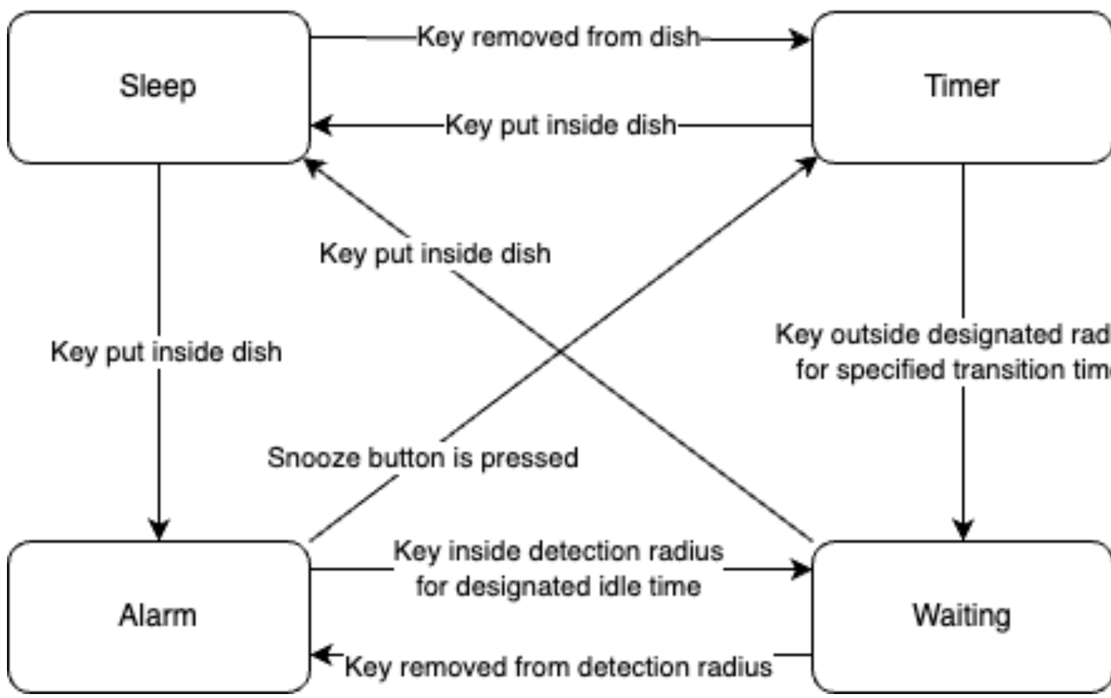


Figure 5: State diagram of dish

| Requirements | Verifications |
|---|---|
| • **Transition between four states when provided appropriate stimuli** | • Simulate software stimuli to ensure sound control logic.<br>• Develop test harness which projects state to an LED. Provide stimuli to change states |

| | |
|---|---|
| | • Test each path to ensure safety of state reachability |
| • **Read input from confirmation subsystem** | • Write test harness to sound an alarm anytime pressure is added to the sensor |
| • **Provide output to sound subsystem**<br>• **Generate 80 Db square waves** | • Write test harness to provide square waves whenever a button is pressed<br>• Compare audible sound with known square wave to ensure correct sound is emitted<br>• Utilize decibel meter to measure loudness right next to the dish |
| • **Read input for proximity detection subsystem** | • Write test harness to sound an alarm whenever the key fob comes within reading range (approximately 15 feet) of the proximity detection subsystem |
| • **Transition state to sleep when snooze button is pressed** | • Simulate an alarm state through a test signal to the processor<br>• Ensure processor is in alarm state through speaker<br>• Press button to see if the alarm turns off |

### 2.3.4 Proximity Detection

Incorporating the DWM1000 modules into the Proximity Detection Subsystem of the Habit-Forming Key Station significantly enhances the system's capability to accurately determine the distance between the key fob and the key station. Each DWM1000 module, one attached to the key fob and the other integrated within the key station, operates within the ultra-wideband (UWB) frequency range of 3.5 GHz to 6.5 GHz. These transceivers communicate using precise time-of-flight (ToF) measurements, enabling the system to calculate the distance between the key fob and the key station with an accuracy of up to 15 feet. This high level of precision is supported by the DWM1000's ability to transmit data at rates ranging from 110 kbps to 6.8 Mbps, catering to various operational demands while ensuring low power consumption. The system operates on a 2.8 V to 3.6 V power supply, making it energy-efficient and suitable for continuous operation [6]. Furthermore, the integration of an SPI interface facilitates seamless communication between the DWM1000 module and the ATtiny84a microcontroller, allowing for efficient data processing and system control.

This dual-module setup leverages the DWM1000's programmable transmitter output power and fully coherent receiver to maintain maximum range and accuracy, ensuring reliable performance even in environments with potential interference from household electronic devices. The compact size of the DWM1000 (23 mm x 13 mm x 2.9 mm) and its integrated antenna simplify the physical design and integration into both the key fob and the key station, minimizing the need for additional RF design efforts. By utilizing the SPI interface for microcontroller communication, the system can dynamically manage the detection and distance calculation processes, adapting to real-time changes in the key fob's location. This intelligent interaction between the DWM1000 modules underpins the subsystem's ability to trigger alerts based on the proximity of the key fob, effectively supporting the system's goal of enhancing user convenience and preventing key misplacement through precise location tracking.

As illustrated in Figure 6, the application circuit provides a practical example of how the DWM1000 module is configured for operational deployment. This schematic demonstrates the connection of the DWM1000 to a host microcontroller through an SPI interface [6], highlighting the necessary power supply considerations and the ancillary components that enable the module's time-of-flight measurement capabilities. The diagram serves as a foundational reference for our Proximity Detection Subsystem, informing the physical design and integration of the DWM1000 modules within both the key fob and the key station. The figure underscores the importance of a coherent receiver and programmable transmitter output power, ensuring that our subsystem can maintain maximum range and accuracy, even in the presence of potential environmental interference.

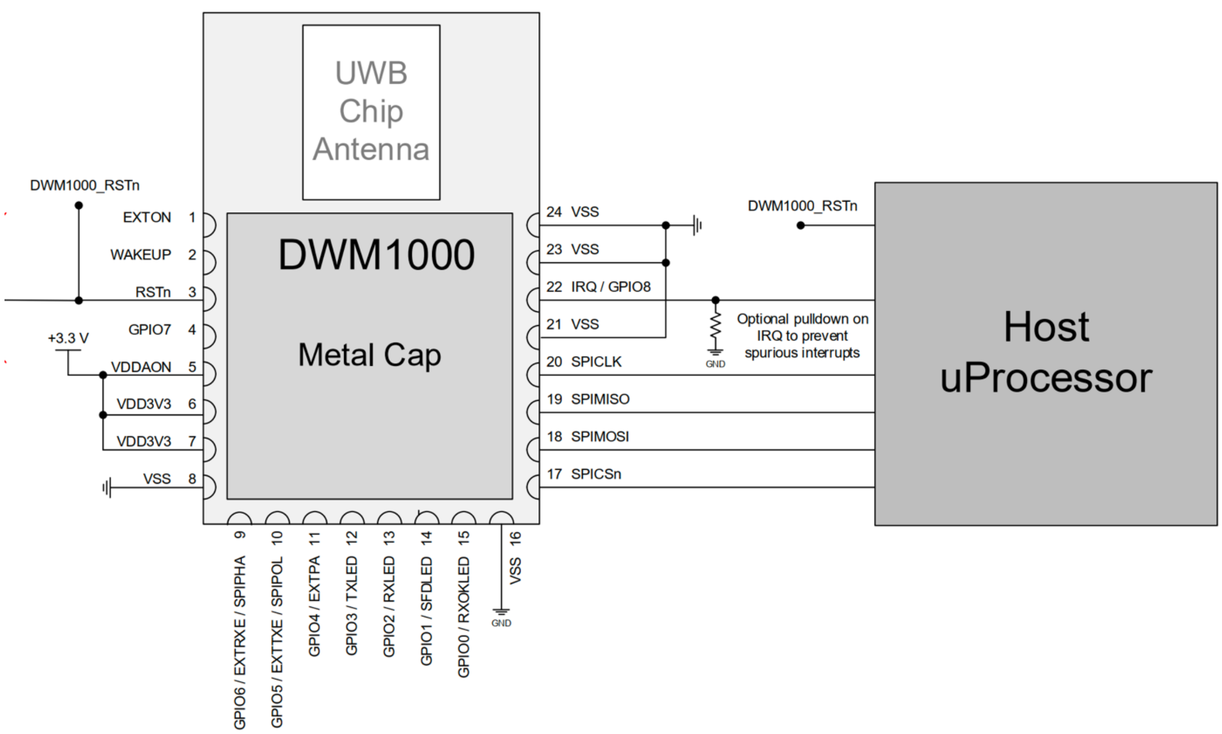


Figure 6: DWM1000 Application Circuits

| Requirements | Verifications |
|---|---|
| **The subsystem shall detect the key fob within a 15 feet radius.** | • Perform a series of detection tests at 1-foot intervals up to 15 feet.<br>• The system must detect the key fob at all distances, with a detection rate of 100% within 15 feet. |
| **The subsystem shall accurately measure the distance of the key fob using time-of-flight calculations.** | • Compare the system's distance measurements against a set of known distances, from 1 to 15 feet, in a controlled environment.<br>• The system's measured distances must have a maximum deviation of less than 5% from the actual distances. |
| **The subsystem shall communicate the key fob's proximity to the Control and Processing Subsystem within 1 second.** | • Verify the communication latency by measuring the time from key fob detection to signal reception by the Control and Processing Subsystem.<br>• The signal indicating the key fob's proximity should be received by the Control and Processing Subsystem within 1 second of detection. |

### 2.3.5 Confirmation

The Confirmation Subsystem for the Habit-Forming Key Station employs the FSR 406, a robust Force Sensing Resistor (FSR) from Interlink Electronics, to detect the placement of keys in the dish through pressure measurement. The FSR 406 is characterized by its ability to respond to force changes ranging from as low as 0.1 Newtons (N) to up to 10N, making it ideal for detecting the slight weight of keys. This square sensor, with dimensions of 43.69mm on each side and a nominal thickness of just 0.54mm, is highly sensitive and provides a highly repeatable force reading with as low as 2% variability for consistent actuation. Its ultra-thin and durable design allows for up to 10 million actuations, ensuring longevity and reliability in the key station application [7]. The FSR's resistance decreases as the force applied to its surface increases, a feature that will be utilized to determine whether keys have been placed in the dish.

To accurately read the pressure applied by the keys, the FSR 406 will be integrated into the key dish in a voltage divider configuration, as recommended for simple force-to-voltage conversion. This setup involves connecting the FSR in series with a measuring resistor, with the output voltage at the junction between the FSR and measuring resistor indicative of the force applied. The output voltage increases with increasing force applied to the FSR surface. As illustrated in figure 7 below [7], the measuring resistor (RM) is selected to optimize the force sensitivity range relevant to the weight of keys and to ensure the current through the FSR is limited to safe levels. The voltage output from this configuration will be fed into an analog-to-digital converter (ADC) on the microcontroller, allowing for digital processing of the force signal. This method facilitates the differentiation between the presence or absence of keys based on the measured force, enabling the system to accurately detect key placement within the dish and to trigger the appropriate system response.

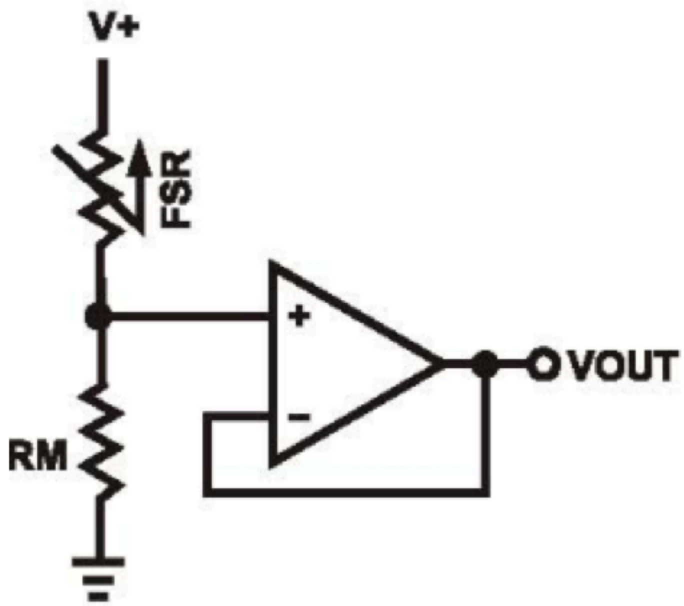


Figure 7: Force-Sensing Resistor Schematic

| Requirements | Verifications |
|---|---|
| **Detect placement of objects weighing between 45g to 55g, simulating key weight, with a tolerance of ±5g.** | • Place an object weighing 50 grams on the pressure sensor to simulate the presence of keys.<br>• The system must recognize the presence of the object as keys within 2 seconds of placement. |
| **The subsystem shall trigger an alarm if the keys are not placed back within 2 minutes after being removed.** | • Remove the keys and wait for 2 minutes to observe if the alarm is triggered.<br>• The alarm must be triggered automatically if the keys are not returned to the pressure sensor within 2 minutes. |
| **The subsystem shall deactivate the alarm within 5 seconds when the keys are placed back on the pressure sensor.** | • Trigger the alarm by removing the keys, then place them back on the sensor to test alarm deactivation.<br>• The alarm must deactivate within 5 seconds of the keys being placed back on the sensor. |

## 2.4 Tolerance Analysis

The following table includes the current draw of every component in our circuits under 3.3V [5] [6].

| Components | Current Draw (mA) | Comments |
|---|---|---|
| ATtiny84A | 200 | DC Current VCC and GND Pin At 125°C |
| DWM1000 | 13.4 | Total Current Draw from all supplies IDLE Mode |
| Total | 213.4 | Sum |

The regulator we will use is LM1117 TO-220, which has the following ratings [2].

| Variable | Value | Comments |
|---|---|---|
| Max Temperature | 150°C | Mas Temperature LM1117 can operate |
| $I_{out}$ | 213.4mA | Calculated Above |
| $V_{in}$ | 12V | Input voltage from the AC-DC Converter |
| $V_{out}$ | 3.3V | Output voltage |
| $T_A$ | 40°C | Ambient Temperature |
| $R_{\theta JA}$ | 23.8°C/W | Junction to Ambient Thermal Resistance |

Using these values, the maximum junction temperature the voltage regulator will reach is calculated as

$ST_J = T_A + PR_{\theta JA}$ = 40°C + (12V – 3.3V) (213.4mA) (23.8°C/W) = 84.18°C

This is well below the maximum junction temperature (150°C) of the voltage regulator. Therefore, the LM1117 TO-220 regulator will output the required power without overheating.

Antenna Delay Calibration Impact

For the DWM1000-based RTLS, the accuracy of location determination is critical. The internal antenna delays $t_{ADTX}$ for transmission and $t_{ADRX}$ for reception can vary due to manufacturing differences, and if not calibrated, can lead to significant errors in the Time of Flight (ToF) calculations.

Theoretical Model

The ToF is given by the equation:

$$TOF = t_{measured} - (t_{ADTX} + t_{ADRX})$$

Given the speed of light c =299,792,458 m/s, the distance d can be calculated by:

$$d = \frac{(TOF \times c)}{2}$$

The factor of 2 accounts for the round-trip of the signal.

Based on the DWM1000's specified temperature coefficient of 2.15 mm/°C, we can express the temperature-dependent delay $\Delta t_{TEMP}$ as:

$$\Delta t_{TEMP} = \frac{(2.15 \times \Delta T)}{c}$$

where $\Delta T$ is the temperature change from the calibration baseline.

The uncalibrated 3-sigma variation in antenna delay was determined to be 30 cm, translating to a delay of:

$$\sigma_{Uncal} = \frac{0.3}{c}$$

After calibration, this variation can be reduced to:

$$\sigma_{cal} = \frac{0.045}{c}$$

These variations lead to a distance error $\Delta d$ before and after calibration:

Before calibration: $\Delta d_{Uncal} = \sigma_{Uncal} \times c$

After calibration: $\Delta d_{cal} = \sigma_{cal} \times c$

The uncalibrated system may see errors up to $\Delta d_{Uncal}$, which is unacceptable for our requirements. Post-calibration, the system can achieve the necessary precision within $\Delta d_{cal}$ under nominal operating conditions.

# 3. Cost and Schedule

## 3.1 Cost analysis

All the parts for the project are outlined in table below include sales tax. The total for these parts is $48.93. If we assume 10% of the total goes towards shipping costs, the total post shipping is $52.83. The average salary of an electrical engineering student at UIUC post-graduation, according to the 2021-2022 Illini Success Report, is $87,769 [8]. This equates to $42.20 per hour. Working on this project for 13 weeks with 25 hours a week amongst the group, the estimated cost for engineers is $13,715. This puts the total cost for parts and labor at $13767.83.

| Description | Role | Manufacturer | Quantity | Extended Price | Link |
|---|---|---|---|---|---|
| ATtiny84A | Microcontroller | Microchip Technology | 1 | 1.62 | Link |
| CMS-251472-24SP | Speaker | CUI Devices | 1 | 1.19 | Link |
| SEN-09376 | Pressure Sensor | Interlink Electronics | 1 | 12.5 | Link |
| L6R12-120 | Power Adapter | Tri-Mage, LLC | 1 | 10.08 | Link |
| LM1117T-3.3 | Voltage Regulator | Texas Instruments | 1 | 1.69 | Link |
| DWM1000 | RF Transceiver | Qorvo | 1 | 17.5 | Link |
| COM-10440 ROHS | Button | Spakrfun | 1 | 2.25 | Link |
| CAB-14166 ROHS | Wire for Button | Sparkfun | 1 | 2.1 | Link |

## 3.2 Schedule

| Week | Task | Person |
|---|---|---|
| February 25th | Receive feedback on design document and refactor schematics accordingly. | Ali H, Cedric M |
| | Complete requirements for PCB review | Marsh M |
| March 3rd | Complete PCB layout to order PCB | Marsh M |
| | Begin control subsystem development | Ali H |
| | Begin Power/Alarm subsystem development | Cedric M |
| March 10th | SPRING BREAK | ALL |
| March 17th | Have keychain PCB completed | Marsh M |
| | Reorder parts / PCB | Ali H |
| | Subsystem development | Ali H, Cedric M |
| March 24th | Control subsystem development completed | Ali H |
| | Proximity/Pressure subsystem development | Marsh M |
| | Power/Alarm subsystem development | Cedric M |
| March 31st | Finish Proximity/Pressure subsystem | Cedric M |
| | Finish Power/Alarm subsystems | Marsh M |
| | Integrate and test all subsystems together | Ali H |
| April 7th | Solder PCB board. Make final changes | ALL |
| April 14th | Mock demo | ALL |
| | Begin final presentation | Cedric M |
| | Begin final paper | Marsh M |
| April 21st | Final demo | ALL |
| | Continue final presentation | ALL |
| | Continue final paper | ALL |
| April 28th | Finish and submit all final requirements | ALL |

## 4. Ethics and Safety

Our design strictly adheres to the principles of respecting privacy and treating all individuals fairly, as outlined by both IEEE and ACM ethics. While our device does track the location of keys, it is done with the sole purpose of functionality enhancement without storing or misusing this data, ensuring users' privacy is safeguarded as described in section 1.6 in the ACM code [9]. For the Power Subsystem, we will ensure safe voltage and current distributions across all subsystems, aligning with ACM's Section 1.2 on avoiding harm, and IEEE's emphasis on safety and risk management [9][10]. Moreover, the design of the alarm's sound level is based on acoustic research to ensure it is loud enough to be effective without causing hearing damage, adhering to ACM's Section 3.1 on prioritizing the public good [9]. The inclusion of a snooze button provides users with control over the alarm, a feature developed with user autonomy and safety in mind, illustrating our adherence to ethical guidelines.

To address potential safety concerns, our design includes fail-safes and protective measures such as voltage regulators to prevent overcurrent and overvoltage situations. A comprehensive lab safety manual, specifically tailored to our project, will be developed and adhered to during all phases of development. This manual will cover safe handling and operational practices for working with electrical components and the 12V power supply. Also, Our choice of a 12V power supply from a standard wall outlet, as opposed to high-voltage or battery-operated systems, minimizes risks associated with high voltage and battery safety concerns, such as thermal runaway.

Our design includes redundant safety checks within the software to detect and respond to potential failures or unsafe conditions, a practice rooted in the ACM's Section 2.5 on thorough evaluations [9]. This approach not only mitigates risks but also aligns with IEEE's call for professionals to be proactive in ensuring the safety, health, and welfare of the public.

By integrating these ethical and safety considerations into our design process, we not only adhere to the codes of conduct set forth by leading professional organizations but also ensure our technology is developed responsibly, prioritizing the well-being and rights of all stakeholders involved.

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