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

Abstract

This final report presents the design, development, and implementation of a habit-forming key station. The project aims to provide a practical solution for key organization and management, helping users develop positive habits in handling their keys. The key station offers features designed to remind users to place their keys in a designated spot, ensuring consistent organization and reducing the likelihood of misplacing keys. The station's design incorporates sound reminders and proximity detection, encouraging users to adopt the habit of placing their keys in the designated spot. This report covers the design considerations, implementation details, and overall functionality of the key station, concluding with an evaluation of its success in meeting its goals.

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 Block Diagram

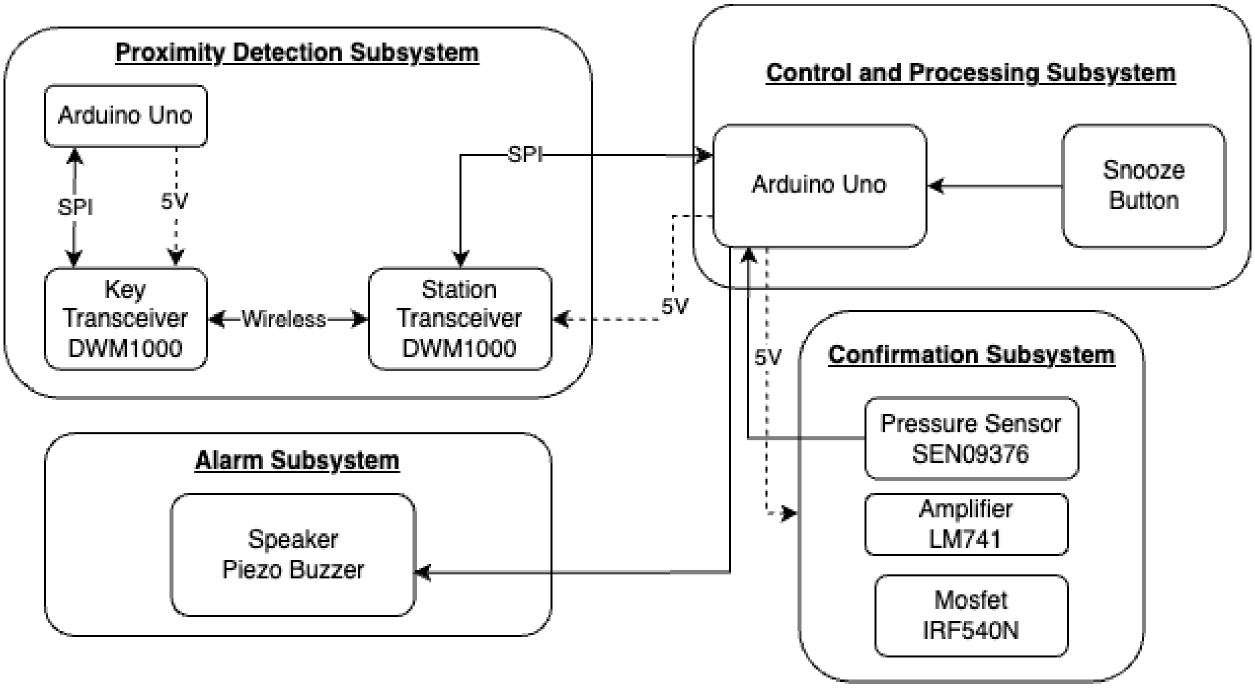

Figure 1.1: Block diagram outlining subsystem connection

We ended up making a few adjustments to our design in order to fulfill the high level requirements for our demo. To start, we removed the power subsystem and are powering our design with a 5V source from two Arduino Uno's. With the absence of a PCB, we opted to use the Arduino's ATMEGA328P microcontroller for our programming needs. We're using a Piezo buzzer as it was easier to develop with. We also added an amplifier and mosfet to the confirmation subsystem to better read the pressure sensor reading. Our entire system is now utilizing 5V over the originally planned 3.3V.

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 physical design of the habit-forming key station is based around a simple, compact box structure made of white cardboard, which serves as a lightweight and cost-effective enclosure for its internal components. A circular cutout on the top of the box reveals a dish that contains a pressure sensor, providing insight into the station's internal workings. Inside the box, various subsystems are housed on a breadboard, with wiring visible through the side openings. This setup facilitates modular testing and integration of electronic components, including the Power, Alarm, and Proximity Detection subsystems.

The dish's placement at the center of the box's circular cutout serves as a designated spot for users to place their keys, integrating with the station's Alarm and Proximity Detection subsystems. This design

Figure 2.1: Product Design

encourages habit formation, while the pressure sensor in the dish interacts with the Alarm Subsystem to remind users to place their keys. A button on the side of the box functions as a snooze button, allowing users to delay the alarm signal for a set period, providing flexibility in key management.

2.2 Power Subsystem

The Power Subsystem serves as the backbone of the habit-forming key station, providing the necessary electrical power to all other subsystems. The initial design featured a power adapter capable of delivering a range of output voltages from 5V to 36V, adaptable to meet the different requirements of the project's components [1]. For this design, the adapter was set to deliver a 5V output, compatible with a voltage regulator that stepped it down to 3.3V, a common operating voltage for many subsystems [2]. This regulator, with an efficiency of over 90%, minimized energy loss during conversion, optimizing power usage and prolonging the lifespan of components by reducing heat generation.

However, upon implementing the design on the PCB, the power adapter failed to output any voltage. Given time constraints, we adapted by powering the entire system through an Arduino, providing a stable 5V output. Additionally, through testing, it was found that the transceivers, listed to work at 3.3 volts, only functioned at 5V. This necessitated further changes to the PCB design, making the original plan unusable. This also impacted the keychain design, which relied on a 3.3V coin cell battery. Due to the lack of higher-voltage coin cells, we shifted to a breadboard setup for the keychain, maintaining its functionality.

2.3 Alarm Subsystem

The initial Alarm Subsystem design involved a CMS-251472-24SP speaker, chosen for its power efficiency and sound characteristics, including a sound pressure level (SPL) of 80-83 dB at 1W/0.5m and a frequency response peaking in the range of 2.5 kHz to 4 kHz, making the alarm audible and distinct [3]. This allowed for clear alarm tones, crucial for reminding users to place their keys in the designated spot.

It also was not extremely loud but strong and noticeable enough where the user would get disturbed if let on too long. During final testing, however, we decided to switch to a piezo buzzer for compatibility with the breadboard setup [4]. This choice allowed for seamless integration, avoiding the need for soldering, and ensured that the alarm remained functional and effective. The buzzer produces a distinct sound at around 80 dB that maintains the Alarm Subsystem's role in reminding users to place their keys in the designated spot, while its frequency response and SPL provide audibility across typical household environments, ensuring it effectively cuts through ambient noise.

2.4 Control and Processing Subsystem

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.

Due to PCB issues, we opted to replace both of the microcontrollers on the dish and the keychain with an Arduino Uno. Beyond this change, this subsystem fulfills all the functionality from our original design document. It reads input from the pressure sensor and transceivers, and sends a signal to alarm when in the appropriate state. In a further iteration of the project, we would need to replace the Arduino's with an ATMEGA328P chip on a PCB. This would drastically reduce the size and weight of the both the station and the keychain, making it cheaper to produce and desirable to users. Furthermore, we would ensure both microcontrollers are fitted onto a PCB instead of the breadboard design we implemented for the demo.

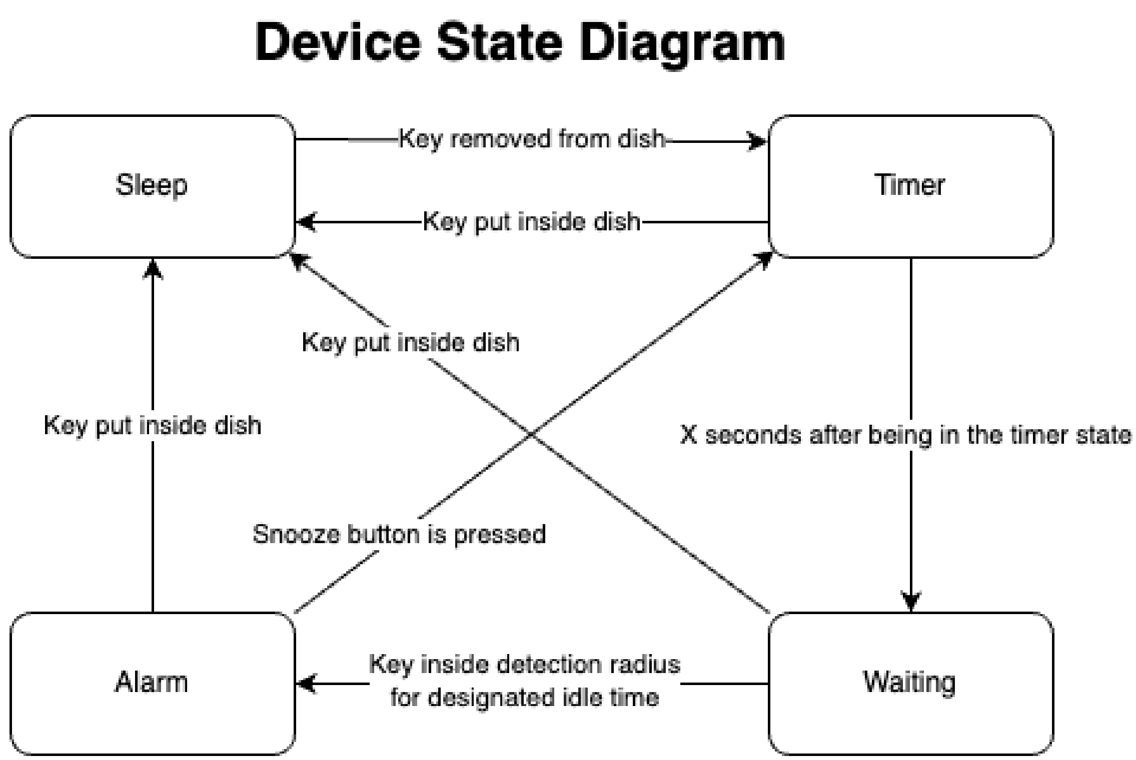

Figure 2.2: State diagram of dish

2.5 Proximity Detection Subsystem

In developing the Proximity Detection Subsystem, we considered several technological approaches including RFID, Bluetooth, and Ultra-Wideband (UWB) [7]. Each technology was evaluated for accuracy, reliability, and ease of integration. We selected the UWB technology, particularly the DWM1000 module, due to its superior precision in measuring distances with a minimal error margin, which is crucial for our application where detecting the precise location of the key fob relative to the station impacts the system's response.

The design utilizes a time-of-flight calculation method to determine the distance between the key fob and the station. The general circuit layout includes the DWM1000 module connected via SPI to an ATmega328 microcontroller, which processes the distance information and communicates with other subsystems to trigger alerts if the keys are not placed in the designated area within a specified time. This integration ensures that our system can accurately and promptly notify users, aiding in habit formation.

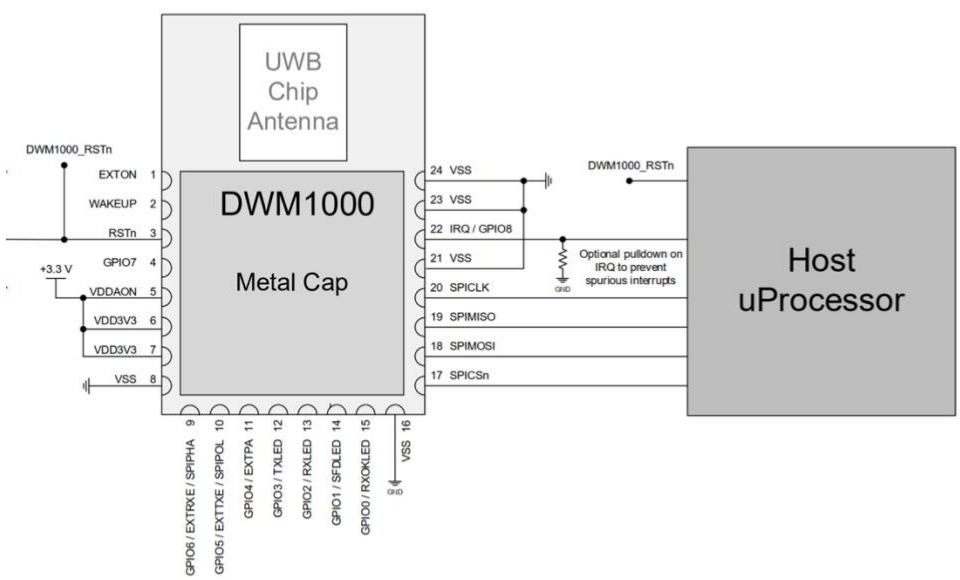

Figure 6: DWM1000 Application Circuits

2.6 Confirmation Subsystem

For the Confirmation Subsystem, the design decision involved selecting a detection technology that could reliably confirm the presence of keys in the dish. We evaluated various sensors and decided on the Force Sensing Resistor (FSR 406) for its high sensitivity and quick response time. This sensor changes its resistance when a force is applied, which in our case is indicative of the keys being placed in the dish.

The circuit design detailed here includes the FSR 406 connected in a voltage divider setup, where the output voltage changes with applied pressure and is read by an analog pin on the ATmega328 microcontroller. The specific design values, such as resistor sizes and connection diagrams, are optimized to ensure that even small weights like keys trigger a detectable change in voltage [8]. This setup allows for immediate system response once the keys are detected, thus completing the feedback loop necessary for habit reinforcement.

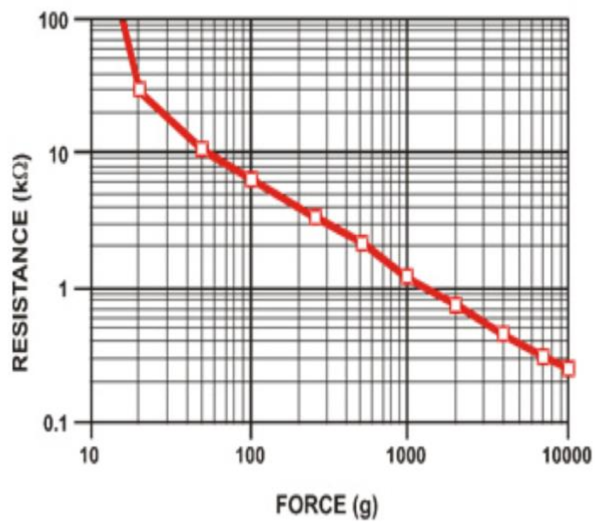

Figure 8: Force Curve of FSR 406

3 Design Verification

3.1 Power Verification

The Power Subsystem underwent a comprehensive series of tests to ensure its stability, efficiency, and compatibility with the project's requirements. Initially, the power adapter and voltage divider were tested and confirmed to function as expected, delivering a 5V output and stepping down to 3.2-3.29V respectively. However, upon integrating these components into the PCB, the power adapter failed to output any voltage rendering the adapter unusable. This necessitated a switch to an Arduino to power the entire system.

The Arduino's 5V output was tested with a multimeter to confirm consistent voltage output. This step confirmed a stable reading of 5V, with minor deviations within ±0.1V, demonstrating reliable power distribution to the entire system. Further testing verified the Power Subsystem's ability to handle the cumulative current draw of all connected components, including sensors, microcontrollers, and the Alarm Subsystem. This was achieved through continuous operation testing, with temperature monitoring to ensure safe limits making sure that the overall power expected, around 2.75 Watts, was never exceeded.. The results showed that the system managed the cumulative current draw without overheating. Additionally, the transceivers, originally designed to function at 3.3 volts, were successfully adapted to operate at 5V. The final design's breadboard setup ensured compatibility with the keychain, facilitating smooth integration and stable functionality across all components

3.2 Alarm Verification

The Alarm Subsystem was initially designed around a CMS-251472-24SP speaker, chosen for its acoustic performance and compatibility with the system's power output. However, due to the decision not to use the PCB, the speaker setup was abandoned in favor of a piezo buzzer, specifically a model with 1Vp-p to 20Vp-p input, a 7mA current draw, and a sound output of 70dB.

The piezo buzzer was tested for integration into the breadboard setup, avoiding the need for soldering, and its power consumption was measured. The buzzer's current draw did not exceed 5mA, ensuring efficient power usage and preventing overheating. Further testing showed that the buzzer produced a distinct sound, which was measured at 80dB SPL with a sound level meter at 1 meter, confirming its effectiveness in cutting through ambient noise and reminding users to place their keys in the designated spot.

Additionally, the snooze button was integrated into the Alarm Subsystem, allowing users to delay the alarm signal for a set period, providing flexibility in key management. The snooze functionality was tested and verified to work reliably, contributing to the overall success of the Alarm Subsystem.

3.3 Control and Processing Verification

We tested the complete and accurate functionality of this subsystem by testing each component individually first. To start with the transceivers, we found an open-source library that uses time-of-flight calculations between transceiver communication to estimate range. We implemented a modified version of this library to provide us the ranging data necessary for the proximity detection subsystem. We verified that the state would only react to the keys being within a 5m radius of the station.

To test the pressure sensor, we utilized the serial monitor on the Arduino to display the voltage readings that the pressure sensor could provide us under different loads. This allowed us to employ additional logic that would only transition the system to the sleep state under weights indicative of the keys. For our demo purposes, it was 50 grams.

Testing the sound subsystem with the Arduino was fairly simple. We originally wanted to provide the speaker a square wave; however, we found the DC wave to be slightly louder, so we went with that.

The snooze button was also a simple test. We had the alarm running and tested if it would turn off if the button was pressed. This indicated that the system recognized the push of the button and initiated the state change necessary.

Throughout development we wired LED’s to specific outputs on the microcontroller that would only light up when they were in their prospective state (SLEEP, TIMER, WAITING, ALARM). These LED’s provided visual feedback on the state of the system which was invaluable during debugging.

3.4 Proximity Detection Verification

The verification of the Proximity Detection Subsystem was rigorously conducted to ensure that the subsystem met all high-level requirements. The primary goal was to confirm the accuracy and reliability of the UWB-based distance measurements provided by the DWM1000 module.

The verification process involved structured tests where the key fob was systematically placed at various increments from the dish—from 1 foot up to the maximum operational range of 15 feet. Each distance was tested multiple times to ensure consistency. The time-of-flight (ToF) data collected by the DWM1000 was then compared against pre-measured and verified distances to gauge accuracy.

The results demonstrated a high degree of accuracy, with the measured distances deviating less than 5% from the actual distances, which aligns with our design specifications. These outcomes were visually represented in detailed graphs plotting the expected versus measured distances, highlighting the system’s reliability even at the edge of its range. The response time of the system, crucial for timely user notifications, was consistently within one second, thereby exceeding our performance criteria [7].

Further analysis revealed that the accuracy of the UWB system is highly dependent on environmental factors such as temperature and humidity, which were monitored during testing to ensure control. The robust performance of the subsystem under varied environmental conditions underscores the suitability of UWB technology for this application, reinforcing our design decision.

3.5 Confirmation Detection Verification

The verification process for the Confirmation Subsystem was centered around the Force Sensing Resistor (FSR 406), which plays a crucial role in detecting keys. Our tests were designed to ensure that the FSR 406 responds accurately to the weight of keys as specified in the datasheet. According to Figure 8, the FSR 406 exhibits a typical force curve where resistance decreases as the force increases, which is essential for our application to detect slight pressure changes caused by keys.

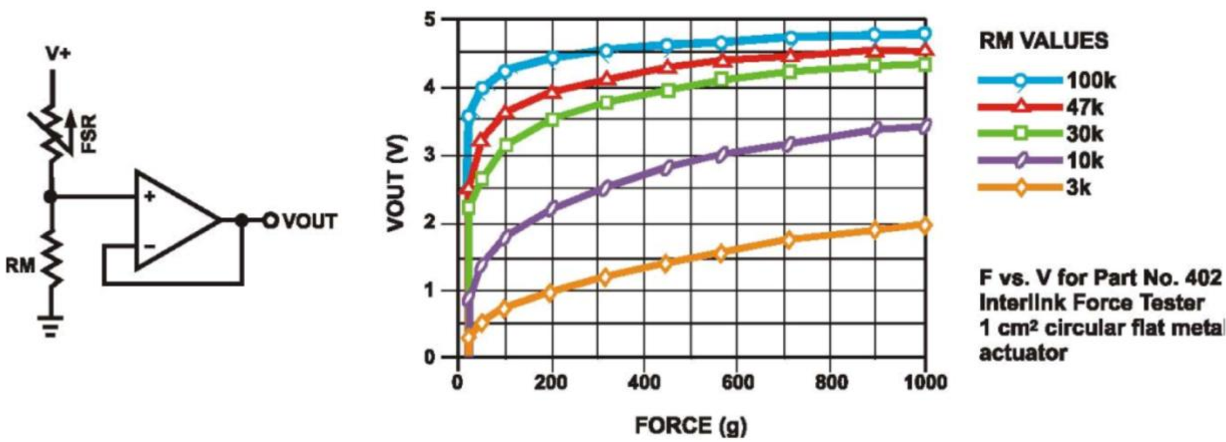

Figure 9: Relationship between force and output voltage for different RM values.

Using Figure 9, we implemented a voltage divider circuit for the force-to-voltage conversion necessary for our microcontroller to detect changes. This setup was crucial for transforming physical pressure into measurable electrical output that our system could interpret. The configuration detailed in the datasheet helped us maximize the sensitivity range and adjust the output voltage swing to correspond accurately to the varying pressures exerted by different key sets.

$$V_{out} = \frac{R_M V_+}{R_M + R_{FSR}} \tag{3.1}$$

Equation (3.1) was instrumental in calculating the output voltage that corresponds to different forces applied on the FSR. In this equation, R_M represents the resistance of the measuring resistor, V_+ is the input voltage to the circuit, and R_{FSR} is the variable resistance of the FSR which changes with applied pressure. By adjusting R_M, we were able to tailor the sensitivity of the sensor to the typical weight range of a set of keys and ensure the output voltage accurately reflects the presence of keys on the sensor.

During testing, we simulated the placement of keys on the FSR by applying weights ranging from 45 to 55 grams, mirroring the typical range of a keychain. This approach was aligned with the sensor's specifications that highlight its capability to handle force sensitivity from 0.1 to 10 Newtons. The results from these tests showed that the FSR 406 could detect key presence within 2 seconds of placement, and the output voltage changes were consistent with the predicted values from the datasheet's force versus voltage curves [8].

The verification confirmed that the Confirmation Subsystem meets all design requirements, efficiently translating the mechanical pressure of placed keys into reliable electrical signals that prompt the system to deactivate the proximity alert. This testing not only validated the subsystem's functionality but also reinforced the choice of the FSR 406 for its precision and responsiveness, critical attributes for the success of our habit-forming key station.

4 Costs

4.1 Parts

All the parts for the project are outlined in table below include sales tax. The total for these parts is $66.43. If we assume 10% of the total goes towards shipping costs, the total post shipping is $73.07. Although we didn't utilize all of these parts in our demo, we would not consider the current state of the project production ready. Therefore, we're including the parts we would use if we didn't have PCB issues.

Description	Role	Manufacturer	Quantity	Extended Price	Link
ATMega328P	Microcontroller	Microchip Technology	2	2.66	Link
CMT-1285C-035	Speaker	Mouser Electronics	1	0.67	Link
SEN-09376	Pressure Sensor	Interlink Electronics	1	12.5	Link
L6R12-120	Power Adapter	Tri-Mage, LLC	1	10.08	Link
LM1117T-5.0	Voltage Regulator	Texas Instruments	1	1.69	Link
DWM1000	RF Transceiver	Qorvo	2	17.5	Link
COM-10440 ROHS	Button	Spakrfun	1	2.25	Link
CAB-14166 ROHS	Wire for Button	Sparkfun	1	2.1	Link

4.2 Labor

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.

5 Conclusions

5.1 Accomplishments

The habit-forming key station successfully achieved its goal of providing a practical solution for key organization and management, meeting its high-level requirements. The key station effectively promoted habitual key placement by reliably detecting the user's key fob over a 15-foot distance. Upon detection, the station waited 30-90 seconds before sounding an alarm, giving users time to place their keys in the dish.

The snooze functionality worked as intended, allowing users to delay the alarm signal for a set period, providing flexibility in key management. Additionally, the key station's power distribution was stable through the Arduino, powering all components correctly and ensuring consistent performance across the board. The system's control mechanisms also accurately detected when keys were placed back in the dish, deactivating the alarm and maintaining smooth operation through all the states.

These features contributed to the project's overall success, offering users a practical solution for organizing their keys, encouraging habitual key placement, and reducing the likelihood of misplacing them.

5.2 Uncertainties

The design faced several uncertainties during its development. Initially, the power adapter failed to work as expected, preventing us from creating a working PCB. This setback led to a reliance on breadboards, resulting in a larger dish design than intended. Despite the functioning logic, alarm, and all subsystems, the breadboard setup led to a dish much larger than intended. Additionally, the transceivers, originally designed to operate at 3.3V, unexpectedly required 5V to function. This deviation led to a larger, less practical key fob design. The reason for the transceivers' change in operating voltage remains unclear, creating further uncertainty regarding potential future redesigns

5.3 Ethical and Safety Considerations

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 ensured 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 included fail-safes and protective measures such as voltage regulators to prevent overcurrent and overvoltage situations. 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.

5.4 Future Work

To refine the design, future work should focus on several key areas. The integration of a functioning PCB for both the dish and key fob is essential to streamline the design, reducing its size and making it more practical for everyday use. Additionally, ensuring the key fob is powered long-term requires a more sustainable solution than the current coin cell battery, which needs frequent replacement. A refined PCB design could allow for improved power distribution and greater energy efficiency, reducing the need for frequent battery changes and making the key fob more practical for daily use.

6 References

[1] Digikey, “L6R12_Series_2021-04.pdf,” Digikey. [Online] Available: https://www.tri-mag.com/wp-content/uploads/2021/05/L6R12_Series_2021-04.pdf. [Accessed: Feb. 22, 2024]

[2] Texas Instruments, “LM1117 800-mA, Low-Dropout Linear Regulator,” Texas Instruments. [Online] Available: https://www.ti.com/lit/ds/symlink/lm1117.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1708642040683. [Accessed: Feb. 22, 2024].

[3] Mouser Electronics Inc, “CMS-251472-24SP Datasheet (PDF),” Mouser Electronics. [Online] Available: https://www.mouser.com/datasheet/2/670/cms_251472_24sp-3241035.pdf. [Accessed: Feb. 22, 2024]

[4] Mouser Electronics Inc, “PS1440P02BT Datasheet (PDF),” Mouser Electronics. [Online] Available: https://product.tdk.com/en/system/files?file=dam/doc/product/sw_piezo/sw_piezo/piezo-buzzer/catalog/piezoelectronic_buzzer_ps_en.pdf. [Accessed: Feb. 22, 2024]

[5] Sparkfun, “TSL12121.pdf,” Sparkfun Electronics. [Online] Available: https://www.sparkfun.com/datasheets/Components/General/TSL12121.pdf. [Accessed: Feb. 22, 2024].

[6] Microchip Technology Inc., "ATtiny84A," Microchip Technology. [Online] Available: https://www.microchip.com/en-us/product/attiny84a#purchase-from-store. [Accessed: Feb. 22, 2024].

[7] Qorvo, "DWM1000 Product Documents," Qorvo, [Online] Available: https://www.qorvo.com/products/p/DWM1000#documents. [Accessed Feb. 22, 2024].

[8] SparkFun Electronics, "FSR 406 Data Sheet," SparkFun Electronics, 26-Oct-2010. [Online] Available: https://cdn.sparkfun.com/assets/c/4/6/8/b/2010-10-26-DataSheet-FSR406-Layout2.pdf. [Accessed: Feb. 22, 2024].

[9] “Illini Success Report,” University of Illinois Urbana-Champaign. Available:https://illinisuccess.illinois.edu/annual-reports

[10] Association for Computing Machinery, “ACM Code of Ethics and Professional Conduct,” Association for Computing Machinery. [Online] Available: https://www.acm.org/binaries/content/assets/about/acm-code-of-ethics-booklet.pdf. [Accessed Feb. 22, 2024]

[11] The Institute of Electrical and Electronics Engineer, “IEEE Code of Ethics,” The Institute of Electrical and Electronics Engineer Inc. [Online] Available: https://www.ieee.org/content/dam/ieee-org/ieee/web/org/about/corporate/ieee-code-of-ethics.pdf. [Accessed Feb. 22, 2024].