ANTI-THEFT SYSTEM FOR CATALYTIC CONVERTER

Team: Theft-Away

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I. EXECUTIVE SUMMARY

1. Target Customer and Market

Anti-Theft Catalytic Converter's targeted customers and markets are vehicle owners, insurance companies, car manufacturers, and thieves.

For vehicle owners, especially those living in areas with high crime rates, the additional layers of protection and alarm will significantly reduce the chance of stolen catalytic converters.

From an insurance company perspective, the rising number of catalytic converter thefts escalates the number of claims for catalytic converter loss. Thus, companies are paying enormous amounts of money, which leads to increased insurance rates. By having catalytic converters reliably protected, insurance companies can be confident that the number of thefts will be significantly reduced, thus allowing them to reduce the insurance rate.

Car manufacturers, by having a protected catalytic converter, can also advertise the system as a premium feature, thus allowing them to sell more cars.

Nevertheless, thieves could also want to get a piece of this Hi-Tech. They may study the system to find a counter-method.

2. Risks mitigated

- Power consumption, even when the ESP-32 continuously operates in normal mode, rarely poses any risk to the car battery capacity.
- Electrical Continuity Sensing system was successfully tested with low latency in triggering and high reliability.
- Email notification system was successfully implemented and tested. Despite some drawbacks such as required Internet to operate, the system can be reliably act as an alternative in case GSM module cannot function as expected.

3. Risk remaining

- Motion sensor, despite being successfully tested in lab environment with range of ~12ft, suffered from high sensitivity, which is only partially resolved, and lack of real-world testing.
- GSM module has not been tested due to difficulty in obtaining the part.
- Our remaining risks include heat transfer from the catalytic converter and heat dissipation from the mechanical housing, sending a phone notification, and material cutting resistance. Though the risk of the chosen material not taking long enough to cut out has been thoroughly reduced.

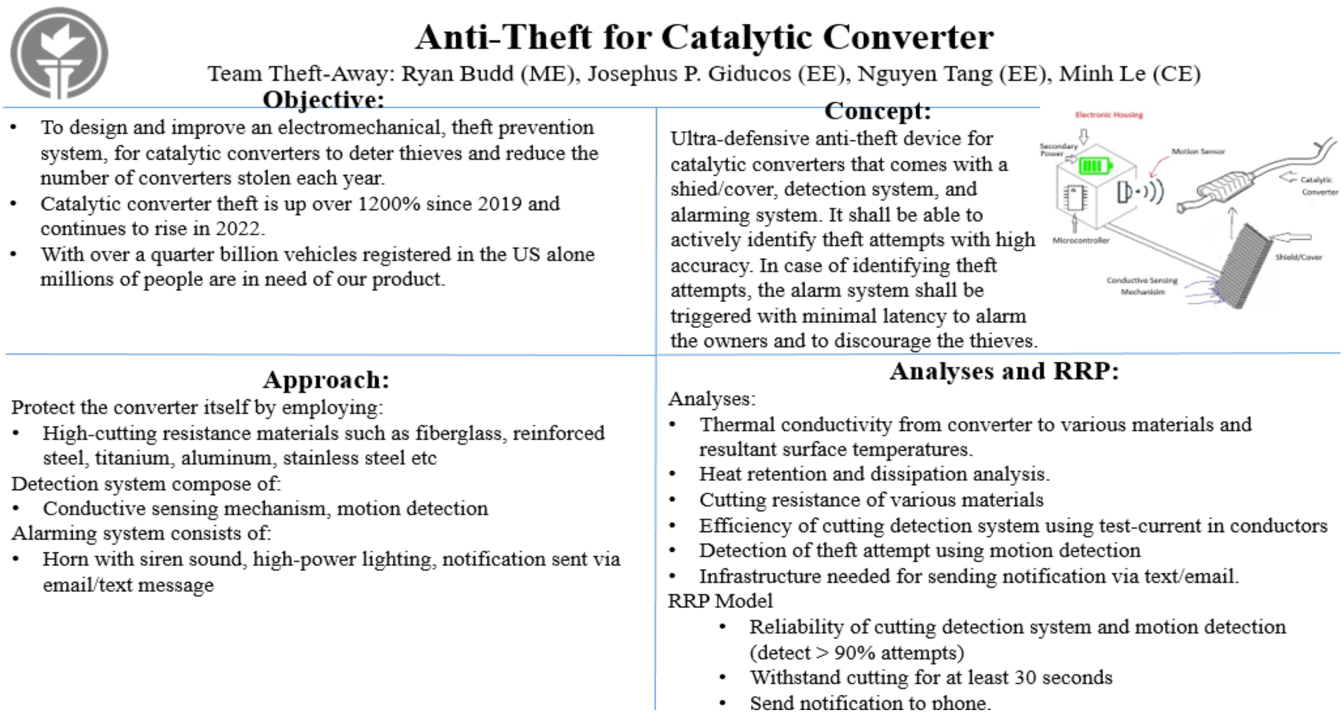
4. Recommended path forward

- Over the winter break, we will work on mitigating the high sensitivity problem of the motion sensor and implementing GSM module. During the first 2 weeks of Winter Quarter, we will meet again and fully test the motion sensor in a real-world setting.
- The project is currently being refined. Many components, such as barcode scanner and lift detection, were removed from our design because of infeasibility, high cost of manufacturing, and overlap with other subsystem functionality. Moreover, many parts were modified to meet our criteria, such as replacing ultrasonic motion sensor with microwave motion sensor to improve reliability.
- During the first week of winter quarter, it will be crucial that we work to mitigate our outstanding risk. Starting with physical tests of our potential heat problem on an actual car and then confirming these numbers on paper and with more testing. We should also source a reciprocating saw and cut material as per RRP spec 004.

5. Key items to address in the first week of winter quarter

- During the first week, we will gather all research and subsystem implementations such as GSM module and motion sensor together, then we will test and integrate all subsystems to ensure functionality of all parts.

II. QUAD CHART



Anti-Theft for Catalytic Converter

Team Theft-Away: Ryan Budd (ME), Josephus P. Giducos (EE), Nguyen Tang (EE), Minh Le (CE)

Objective:

- To design and improve an electromechanical, theft prevention system, for catalytic converters to deter thieves and reduce the number of converters stolen each year.
- Catalytic converter theft is up over 1200% since 2019 and continues to rise in 2022.
- With over a quarter billion vehicles registered in the US alone millions of people are in need of our product.

Concept:

Ultra-defensive anti-theft device for catalytic converters that comes with a shied/cover, detection system, and alarming system. It shall be able to actively identify theft attempts with high accuracy. In case of identifying theft attempts, the alarm system shall be triggered with minimal latency to alarm the owners and to discourage the thieves.

Approach:

Protect the converter itself by employing:
- High-cutting resistance materials such as fiberglass, reinforced steel, titanium, aluminum, stainless steel etc

Detection system compose of:
- Conductive sensing mechanism, motion detection

Alarming system consists of:
- Horn with siren sound, high-power lighting, notification sent via email/text message

Analyses and RRP:

Analyses:
- Thermal conductivity from converter to various materials and resultant surface temperatures.
- Heat retention and dissipation analysis.
- Cutting resistance of various materials
- Efficiency of cutting detection system using test-current in conductors
- Detection of theft attempt using motion detection
- Infrastructure needed for sending notification via text/email.

RRP Model
- Reliability of cutting detection system and motion detection (detect > 90% attempts)
- Withstand cutting for at least 30 seconds
- Send notification to phone.

Figure 1. Updated Quad Chart

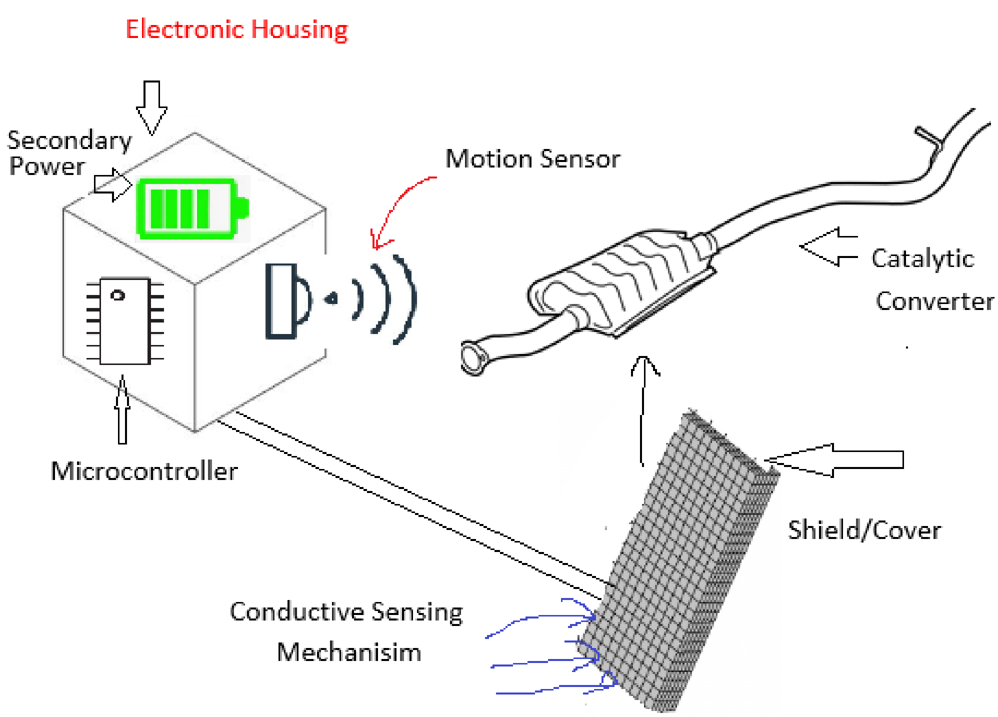


Figure 2. Rough sketch of the project

III. RISK REDUCTION PROTOTYPE DESCRIPTION

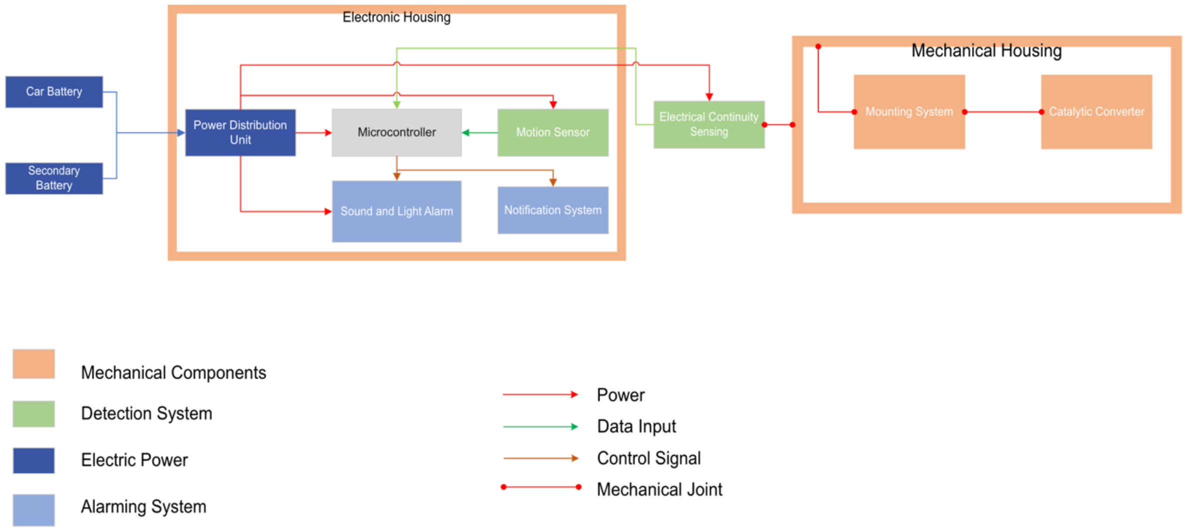


Figure 3. Updated Block Diagram

The catalytic converter is encased in a mechanical housing composed of high cutting resistance material such that in case of theft, the housing shall not be cut easily, thus other protection mechanism can activate against theft. However, to ensure proper operation of catalytic converter, the housing is also designed to radiate the heat from the converter away.

Outside of the mechanical housing, an electrical continuity sensing mechanism, which composes of a grid of energized electrical wires, is placed outside of the housing. When one of the wires is cut, the microcontroller, which is placed at another place, senses the de-energizing wire and triggers the alarm mechanism.

Because of high-heat nature of catalytic converter, microcontroller, motion sensor, and alarming system are placed in another housing away from the converter. In active mode, the motion sensor identifies suspicious motions under the car and notifies the microcontroller. Upon detecting a theft attempt, the microcontroller fires up sound and light alarms while also notifying the user via notification system.

To provide redundancy to the system, the electronic subsystems use 2 power sources: car battery and a secondary battery. The two power sources are connected to other electronic components via a power distribution unit. Normally, the car battery is used. However, when the car battery is low in capacity, the power distribution unit automatically switches to secondary battery for power sources. The power distribution unit also frequently check for battery status of both sources. Thus in case one of the two power sources is disconnected due to theft or unintended damage, the distribution unit can sense the loss of power and notify the microcontroller.

IV. RISK REDUCTION PROTOTYPE SPECIFICATIONS:

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Relates to critical feature(s)
RRP001	Detection accuracy of the microwave radar motion sensor	80%	95%	Each attempt lasts for 3 seconds, counting number of successes out of 20 attempts	Demonstrates the efficiency of the motion sensor	2, 3
RRP002	Detection accuracy of the electrical continuity sensor	80%	95%	Each attempt lasts for 3 seconds, counting number of successes out of 20 attempts	Demonstrates the efficiency of the sensing mechanism	2, 3
RRP003	Thermal resistivity and component Isolation	Keep sensitive electronics under 75 degrees C, while being subjected to a >=600F environment for at least 5 minutes	Keep sensitive electronics under 60 degrees C, while being subject to a >=800F environment for at least 5 minutes	Use MAPGAS or propane torch to create a simulated thermal environment. Place mechanical housing material and other shielding between the electronics and heat source. (no contact with housing) Measure electronic temperature with a digital heat sensor	This will demonstrate the ability of the housing to thermally isolate the electronics and allow them to function at acceptable operating temperatures.	1

RRP004	Material cutting resistance	Take at least 30 seconds to cut completely through two ends of housing material using reciprocating saw.	Take at least two minutes to cut completely through two ends of housing material using reciprocating saw	Physical test on housing material with a reciprocating saw	On average current systems increase the time it takes thieves to cut out the converter by approximately 30 seconds we seek to improve on that time.	1
RRP005	Time from triggering phone messaging to receiving message on phone	<60s	<15s	Use timer	Prove the ability to quickly send message in case of theft	3

Table 1. List of RRP Specifications

1. Detection accuracy of the microwave radar motion sensor

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Relates to critical feature(s)
RRP001	Detection accuracy of the microwave radar motion sensor	80%	95%	Each attempt lasts for 3 seconds, counting number of successes out of 20 attempts	Demonstrates the efficiency of the motion sensor	2, 3

```
from machine import Pin, ADC
import time
led = Pin(2, Pin.OUT);

adcPin = Pin(4,Pin.IN)
adc = ADC(adcPin)
while True:
    val = adc.read_u16();
    print(val);
    if val == 65535:
        led.on()
    else:
        led.off()
    time.sleep(0.5)
```

Figure 4. Code for controlling RCWL-0516 motion sensor

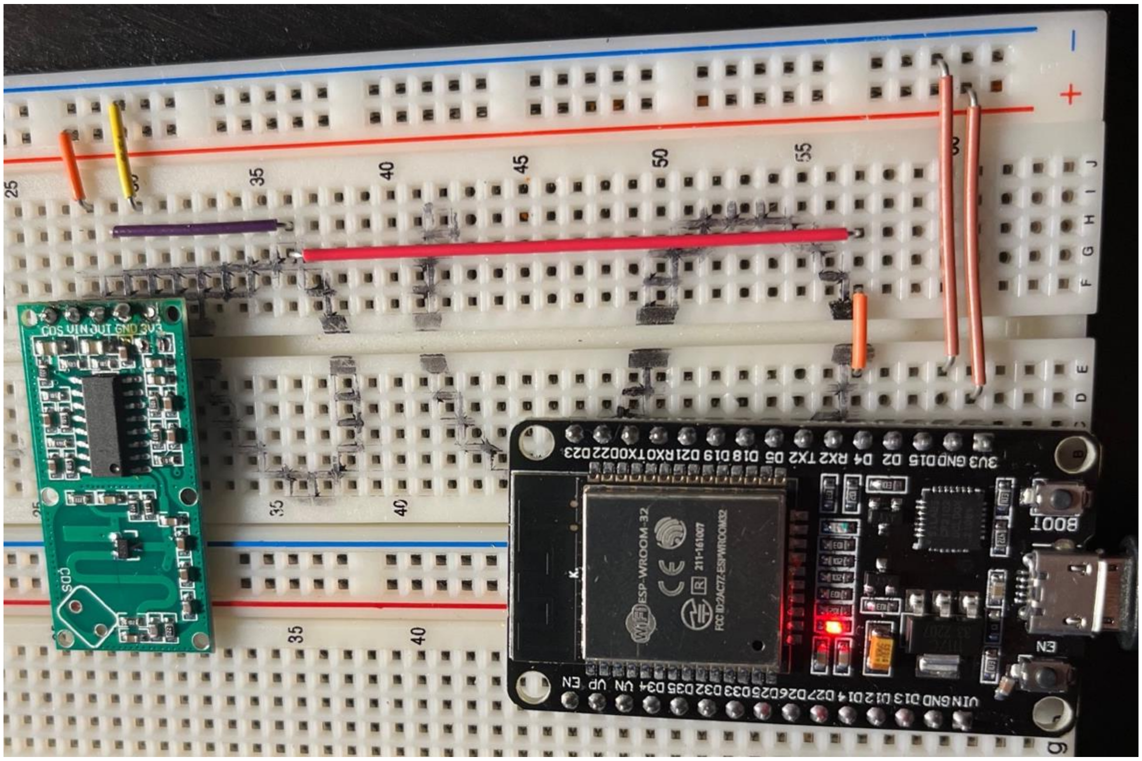


Figure 5. Hardware implementation of RCWL-0516 sensor and ESP-32 microcontroller

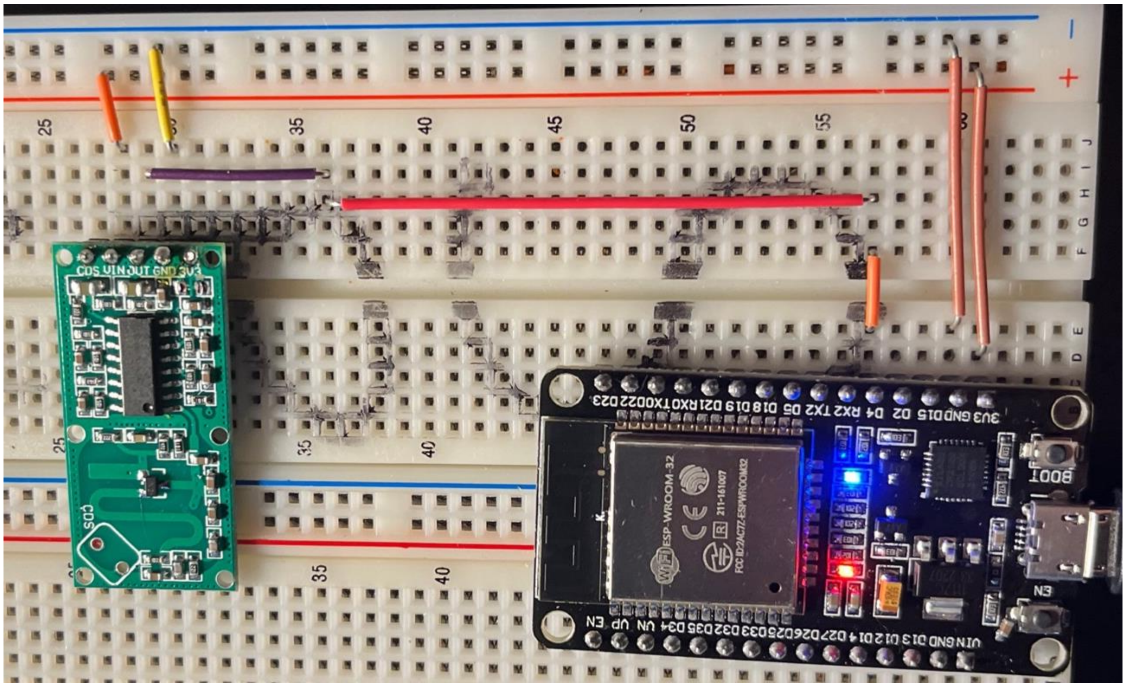


Figure 6. On-board LED triggered when motion was detected

Figure 7. Set up of test for operation of RCWL-0516 microwave motion sensor

At still condition in lab environment, while recommended voltage range for RCWL-0516 is 4-28V, the sensor was underpowered at 3.3V. Despite that, the sensor was operating precisely at distance below 12ft from its front. Out of 20 attempts, the sensor was triggered with less than 1 second of latency from when the motion started.

However, the sensor sensitivity is too high, which leads to multiple false triggers of approximately 4-5 false triggers during each testing attempt. The false triggering was mitigated by adding sleeping time of 0.5 seconds at each loop to allow calibration time after each attempt. The false triggering rate was significantly reduced to 1 false trigger after 4 attempts. The false triggering may be further mitigated by implementing software filter and statistical processing to identify and remove false triggering. We will further refine and test the effectiveness of the software solution over the winter break.

Another mitigation method is adding a 1MΩ resistor to the back of the sensor. But due to lack of equipment, including high-heat soldering iron and small surface-mount 1MΩ resistor, at the lab, we were unable to test this method.

2. Detection accuracy of the electrical continuity sensor

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Relates to critical feature(s)
RRP002	Detection accuracy of the electrical continuity sensor	80%	95%	Each attempt lasts for 3 seconds, counting number of successes out of 20 attempts	Demonstrates the efficiency of the sensing mechanism	2, 3

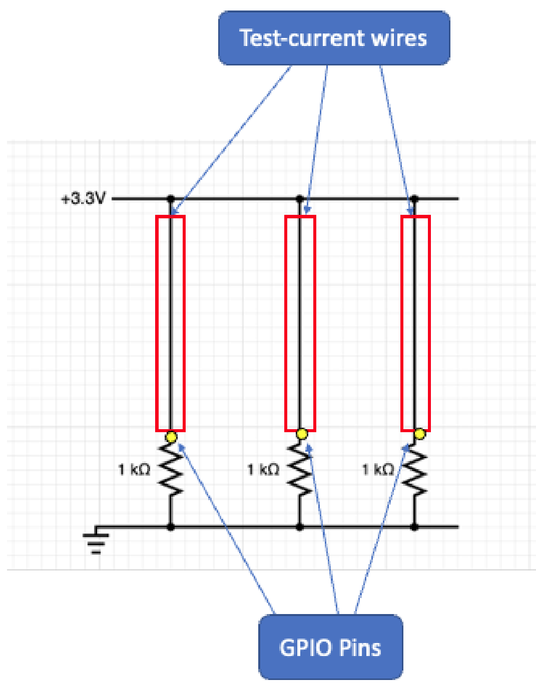


Figure 8. Electrical schematic of Conductive Sensing Mechanism

```python
from machine import Pin
import time

# led mimic alarm system
buzzer = Pin(2, Pin.OUT)


wire1 = Pin(25, Pin.IN, Pin.PULL_DOWN)
wire2 = Pin(26, Pin.IN, Pin.PULL_DOWN)
wire3 = Pin(27, Pin.IN, Pin.PULL_DOWN)

wire_list = [wire1, wire2, wire3]


while True:
    for wire in wire_list:
        if (wire.value() == 0):
            buzzer.on();
            break
        buzzer.off();
```

Figure 9. Software implementation of Conductive Sensing Mechanism

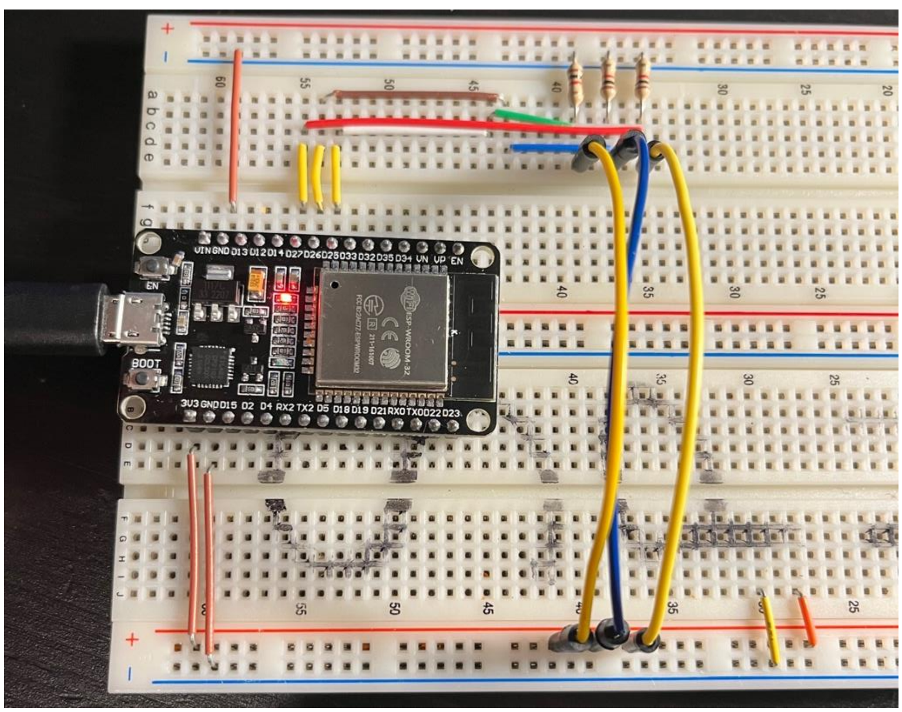


Figure 10. Hardware implementation of Conductive Sensing Mechanism (in off-state)

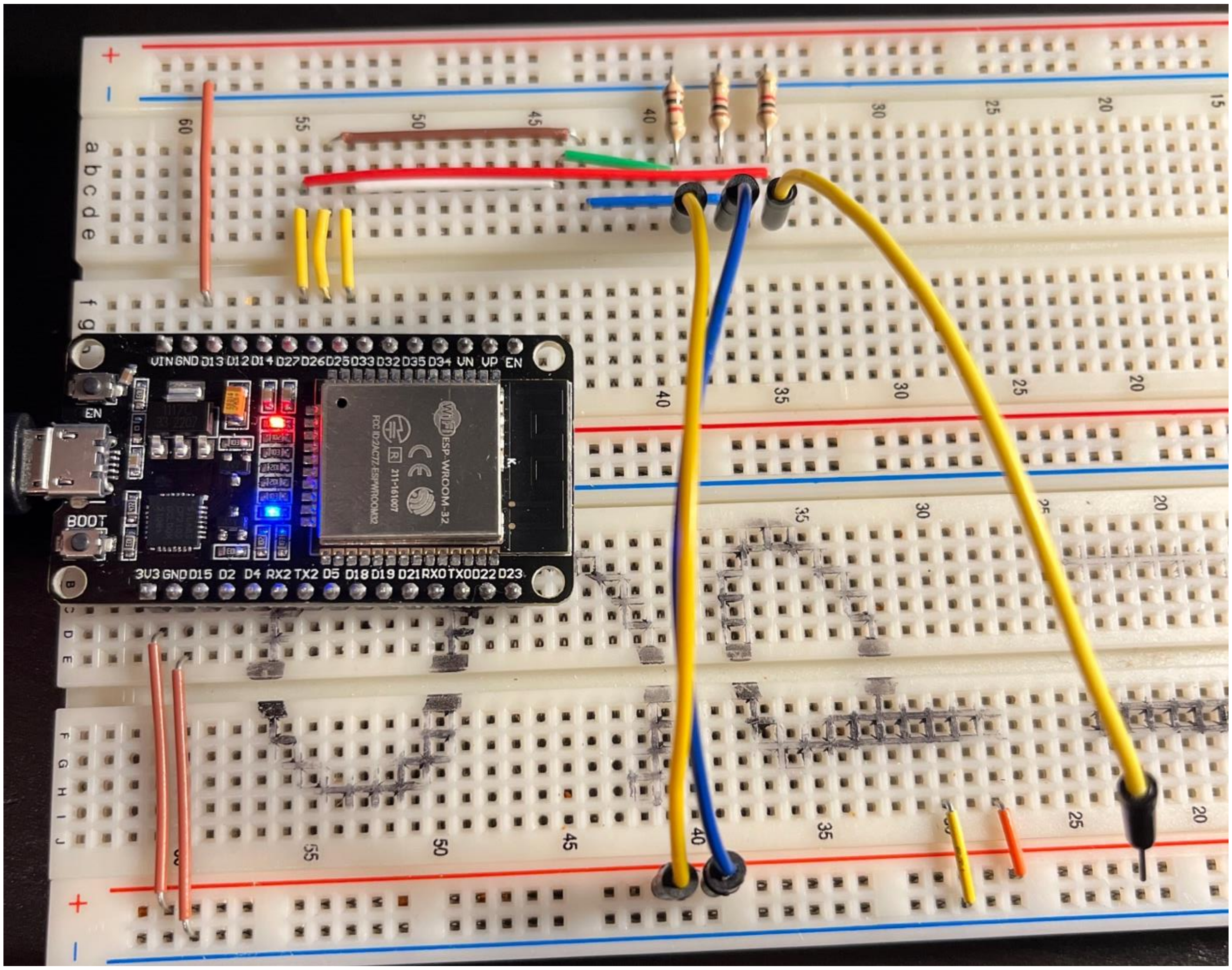


Figure 11. Conductive Sensing Mechanism in triggering state when one of the test wires was removed

Out of 20 attempts, the electrical continuity test always triggered with almost no latency. The conductive sensing mechanism did not trigger any false alarm; thus, its reliability and effectiveness were successfully tested and proven.

3. Thermal Resistivity and Component Isolation

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Relates to critical feature(s)
RRP003	Thermal resistivity and component Isolation	Keep sensitive electronics under 75 degrees C, while being subjected to a >=600F environment for at least 5 minutes	Keep sensitive electronics under 60 degrees C, while being subject to a >=800F environment for at least 5 minutes	Use MAPGAS or propane torch to create a simulated thermal environment. Place mechanical housing material and other shielding between the electronics and heat source (no contact with housing). Measure electronic temperature with a digital heat sensor	This will demonstrate the ability of the housing to thermally isolate the electronics and allow them to function at acceptable operating temperatures.	1

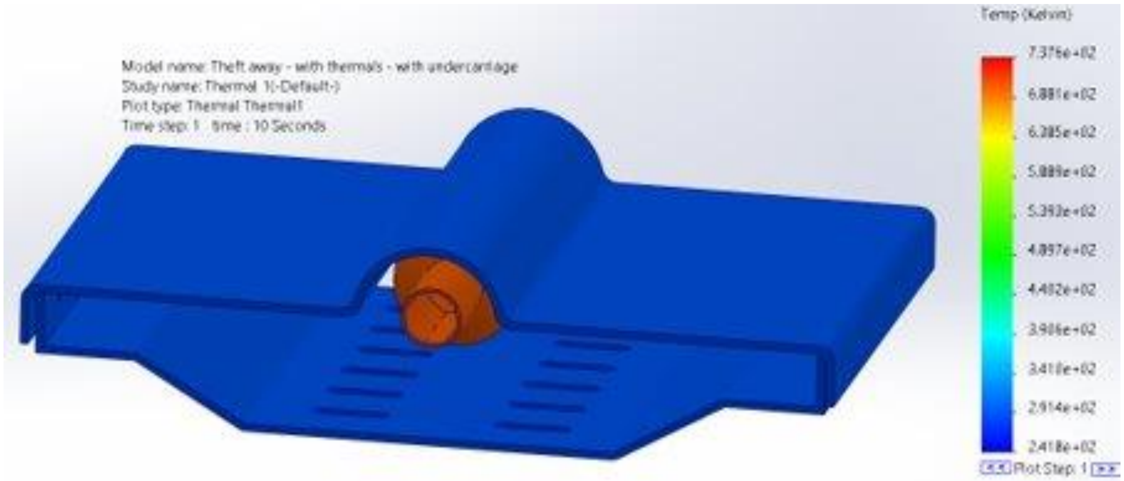


Figure 12. Temperature of the catalytic converter and the surrounding mechnical housing and undercarriage of the car at t = 1

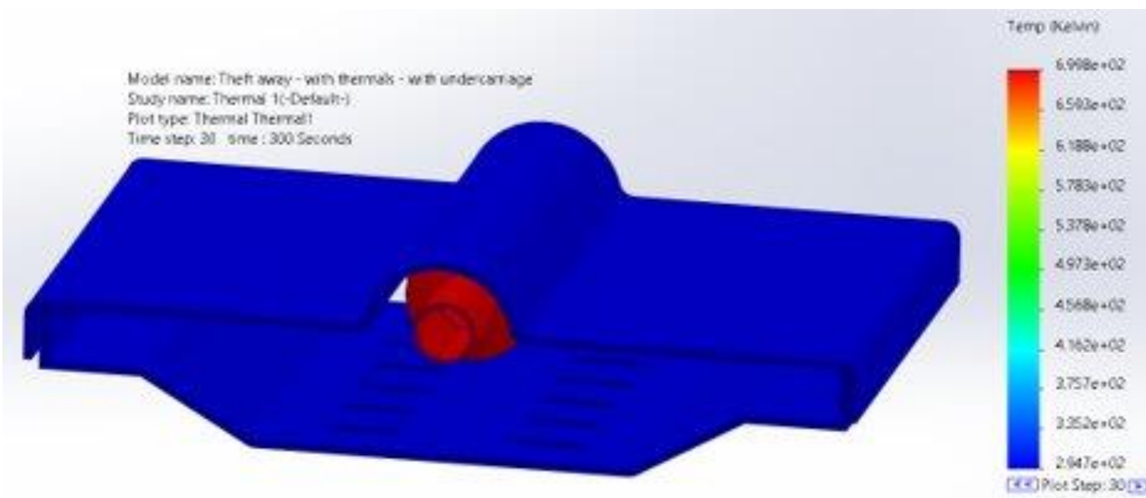


Figure 13. Temperature of the catalytic converter and the surrounding mechanical housing and undercarriage of the car at t = 30 or 5 minutes.

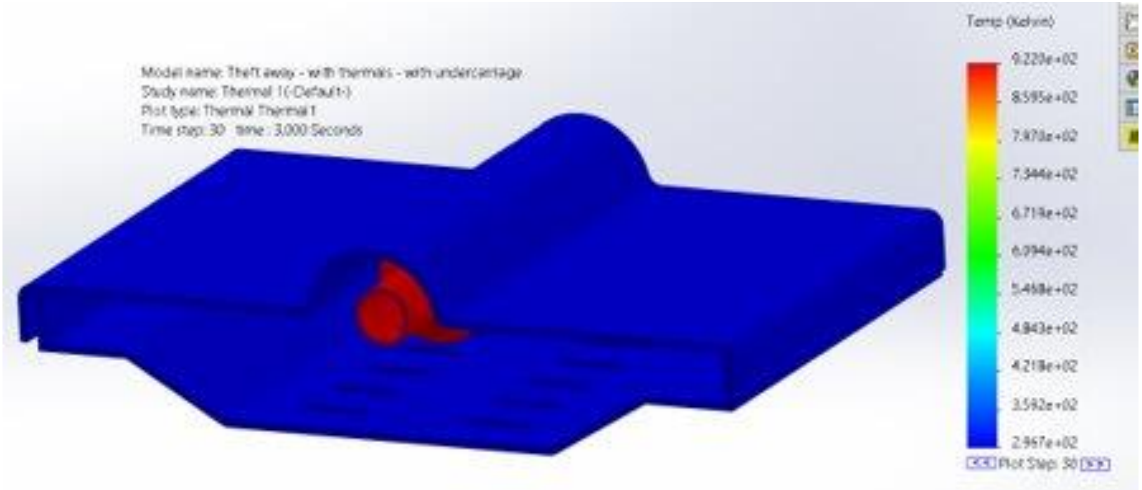


Figure 14. Temperature of the catalytic converter and the surrounding mechanical housing and undercarriage of the car after 50 minutes.

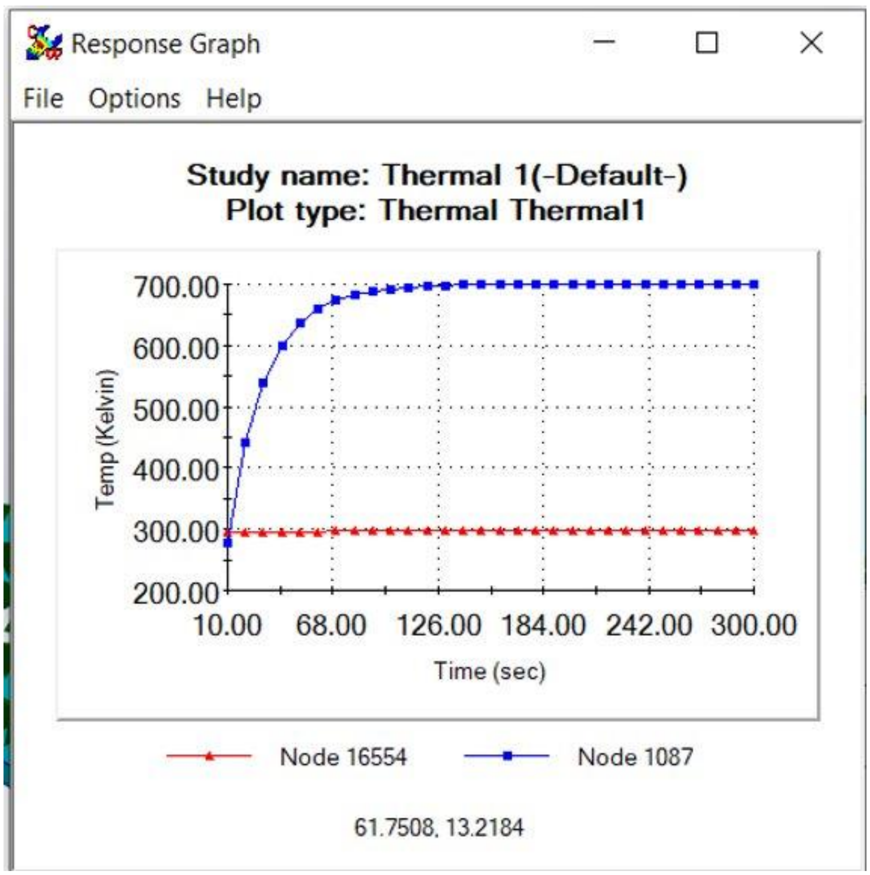


Figure 15. Time response plot for the temperature of the surface of the catalytic converter (Blue) and the mechanical housing (red) over 5 minutes.

4. Material Cutting Resistance

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Relates to critical feature(s)
RRP004	Material cutting resistance	Take at least 30 seconds to cut completely through two ends of housing material using a reciprocating saw.	Take at least two minutes to cut completely through two ends of housing material using reciprocating saw	Physical test on housing material with a reciprocating saw	On average current systems increase the time it takes thieves to cut out the converter by approximately 30 seconds we seek to improve on that time.	1

Material choice has been majorly narrowed down to an aluminum alloy, most likely 6061 – T6 and a high strength stainless steel allow such as 304.

In order to cut out the catalytic converter, thieves will have to cut out the mechanical housing completely, as the housing will not allow the converter to slide out. Alternatively they cut out one face of the housing completely, potetially allowing the converter to slide out. Either way the thief will have to cut through, at minimum, a foot of metal before getting to the converter.

Using and angle gridner or circluar saw it is pretty simple to cut through aluminum and does the job pretty quickly. Angle grinders, In my experience, can cut through aluminum at around an inch per second. Reciprocating saws will be, in most scenarios, much slower to cut the converter out, regardless of the chosen material.

Since our group was unable to test stainless steel, which we know will provide much more cutting resistance than aluminum, For the sake of explanation we will assume the cutting reistance of low carbon steel and stainless steel to be the same or similar. In my experience low carbon steel takes much longer to cut than aluminum, in most cases around 6 times longer. For aluminum at 1inch persecond a person could cut out a one foot cube in 48 seconds, however, with stainless stell, this would take 4 miutes and 48 seconds.

Future

In the next few weeks, either over winter break, or during the first week of winter quarter our team plans to run physical tests on aluminum and potentially stainless steel to determine the actual cutting resistance of these materials in terms of amount of time to cut in inches per second. This wil be semi-imporatnt in finding the right material to design the mechanical housing around, although thermal properties are still the major component of the RRP.

5. Phone messaging system

Spec ID	Requirement	Threshold (Shall)	Objective (Should)	Validation Method	Why this threshold value	Relates to critical feature(s)
RRP005	Time from triggering phone messaging to receiving message on phone	<60s	<15s	Use timer	Prove the ability to quickly send message in case of theft	3

```
import network, urequests, machine, sys
import time
import esp, gc

esp.osdebug(None)
gc.collect()

ssid = "CenturyLink6418"
pas[redacted]vk9a"
api[redacted]J7x77AURvRP9kk_n6qF-U3Q3nvQ2W"
event = [redacted]

stat[redacted]

station.active(True)
station.connect(ssid, password)

while station.isconnected() == False:
    pass
print("Connected")
print(station.ifconfig())
request_header = {'Content-Type': 'application/json'}

start = time.time()
request = urequests.post(
    "https://maker.ifttt.com/trigger/" + event + "/json/with/key/" + api_key,
    json={},
    headers=request_header)
print(request.text)
request.close()
end = time.time()
print("Request take: " + str(end-start) + "s")
```

Figure 16. Software for sending email notification to phone

```
>>> %Run -c $EDITOR_CONTENT

  Connected
  ('192.168.0.44', '255.255.255.0', '192.168.0.1', '192.168.0.1')
  Congratulations! You've fired the notification json event
  Request take: 2s
```

Figure 17. A conducted test case

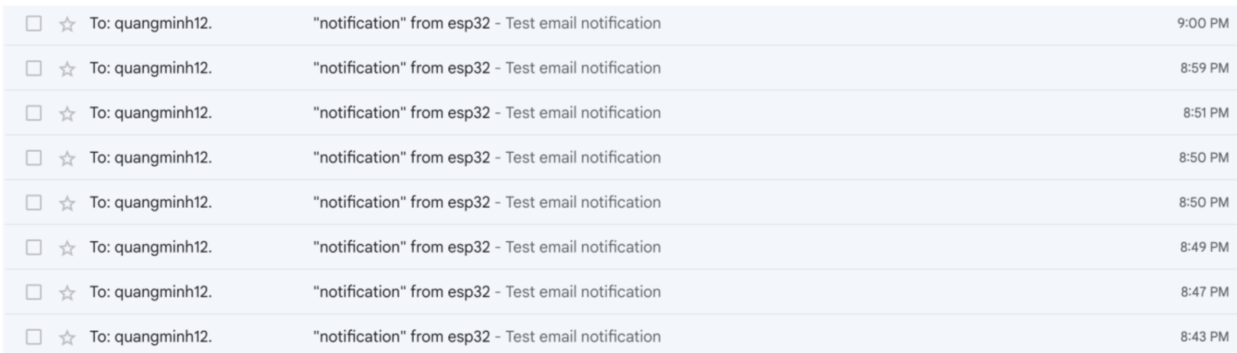


Figure 18. List of sent emails between 8:43PM to 9:00 PM from test server

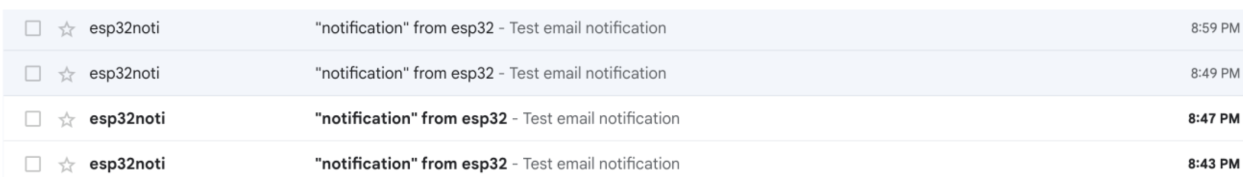


Figure 19. List of received emails between 8:43PM to 9:00PM at destination emails

For our RRP, because of a delay in shipping GSM module, we were unable to test the messaging from an actual phone number. Instead, we implemented an email notification system to demonstrate the ability of sending messages.

When sending message to phone, although the software correctly triggered the server to send notification to destination email within 2 seconds, it appeared the destination email server, which was Gmail during our testing, filtered out emails that were sent in a short time duration. From testing, it is estimated that any two consecutive email notification must be at least 2 minutes apart to bypass the default filter of Gmail server, as indicated in figures above

Out of 20 attempts, when the 2-minute rule was being kept, the software successfully sent notifications, and the destination email successfully received them within 2 seconds and below. Thus, with a reliable internet connection, it is confident that our email notification implementation works efficiently and reliably.

While this method of sending message won't be our final subsystem implementation, the email sending software will act as an alternative in case our GSM module cannot operate as we expected.

V. ENGINEERING ANALYSES

1. Power Consumption

```
CP2102 USB to UART Bridge Controller:

  Product ID: 0xea60
  Vendor ID: 0x10c4  (Silicon Laboratories, Inc.)
  Version: 1.00
  Serial Number: 0001
  Speed: Up to 12 Mb/s
  Manufacturer: Silicon Labs
  Location ID: 0x01120000 / 7
  Current Available (mA): 500
  Current Required (mA): 100
  Extra Operating Current (mA): 0
```

Figure 20. Current measurement obtained from Mac Teminal

From the figure above, the ESP-32 and detection system, which draws power from ESP-32 to operate, requires 100 mA of current from the computer. As specified in Apple specifications, USB port outputs 5V voltage, thus the total power to ESP-32 in normal operating mode is:

$$P_{normal} = 5V * 100mA = 500mW$$

A car battery outputs 12V of power, thus the required current for ESP-32 board is:

$$I_{ESP32} = \frac{P_{normal}}{12V} = \frac{500mW}{12V} \simeq 42mA$$

A car starer motor typically draws a maximum current of 225A [1] over 15 seconds to start the engine, thus it requires a battery capacity of:

$$Minimum\ capacity = 225A * \frac{15s}{3600\frac{s}{h}} \simeq 0.9375Ah$$

Using a safety factor of 1.5, the required capacity to safely start a car is:/

$$Require\ capacity = 0.9375Ah * 1.5 \simeq 1.4Ah$$

A typical car battery has battery capacity of 55Ah [2]. When excluding the capacity requires to safely start a car, the remaining battery is:

$$Remain\ capacity = 55Ah - 1.4Ah = 53.6Ah$$

Suppose only half of the remain capacity can be used for ESP-32, the total running time of ESP-32 when operating in normal mode is:

$$Running\ time = \frac{Remain\ capacity/2}{I_{ESP32}} = \frac{53.6Ah/2}{42 * 10^{-3}A} \simeq 638\ hours = 26.5\ days$$

Thus, even when operating in normal mode, ESP-32 can still operate up to 26.5 days without draining all the car battery.

Moreover, because a car battery can safely output up to 225A of current, the amount of current is enough to safely trigger alarming system.

2. Microcontroller

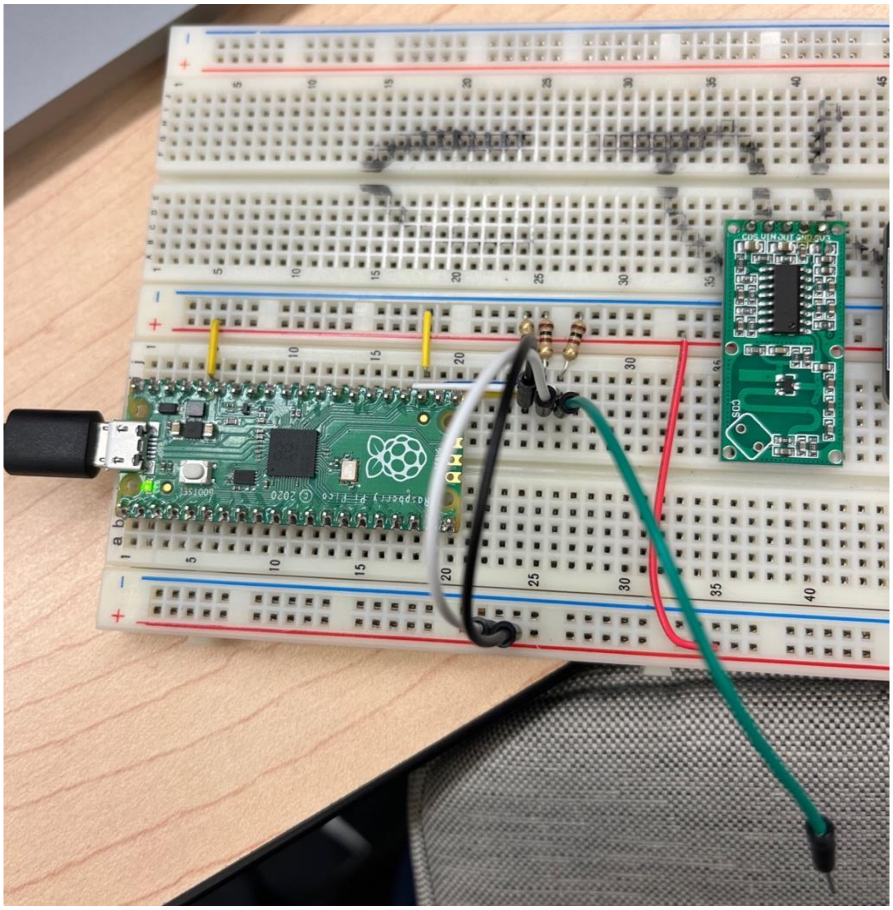


Figure 21. Raspberry Pi Pico implementation

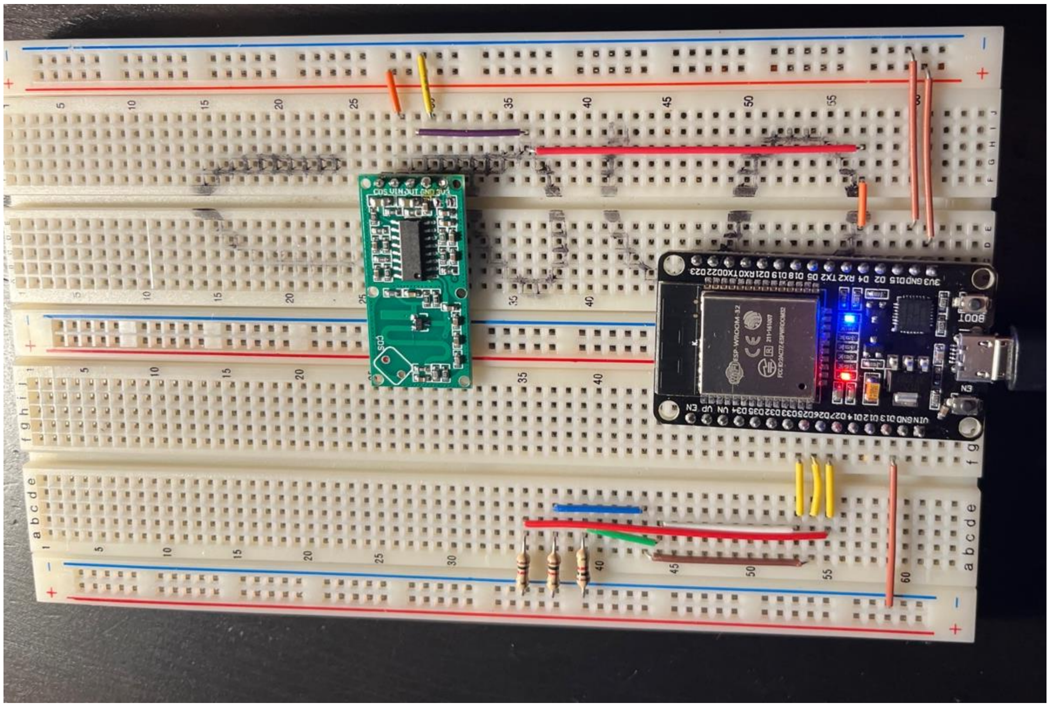


Figure 22. ESP-32 implementation

At first, the electronic subsystem was built based on Raspberry Pi Pico because of Pico's simplicity. However, as more features are required, GPIO pins limited power output (<16mA per pin and <51mA total) and the lack of ADC pins significantly limited our design. Furthermore, Raspberry Pi Pico is only compatible with Raspberry-based sensors, thus the choice of sensors is also limited.

Therefore, ESP-32 was selected as an alternative to Pi Pico. ESP-32 is equipped with 18 ADC channels, 22 usable GPIO pins, and dual Wi-Fi and Bluetooth capability. Some GPIO pins can be configured to output 40mA of current, thus sensors can be directly driven using current from GPIO pins. The board also supports all sensor connection modes such as SPI, UART, I2C, etc. Moreover, because ESP-32 is built based on Arduino architecture while also supporting MicroPython as Raspberry Pi Pico does, the board is compatible with a wider range of sensors.

3. Motion sensor

```
from machine import Pin, ADC
import time
led = Pin(2, Pin.OUT);

adcPin = Pin(4,Pin.IN)
adc = ADC(adcPin)
while True:
    val = adc.read_u16();
    print(val);
    if val == 65535:
        led.on()
    else:
        led.off()
    time.sleep(0.5)

```

Figure 23. Sleeping time during each loop execution

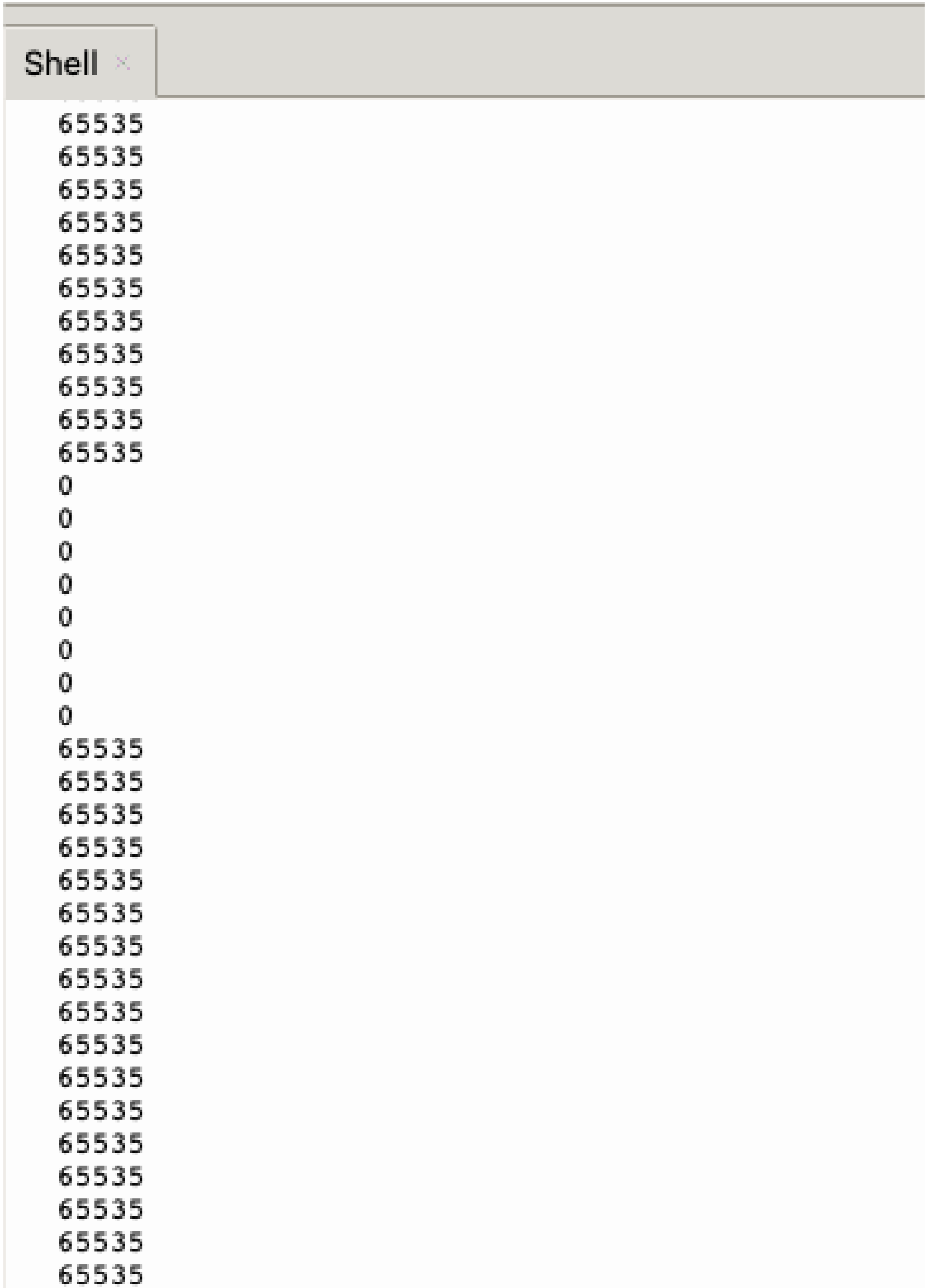


Figure 24. Adjusting sleeping time to 0.1s

```
MicroPython v1.19.1 on 2022-06-18; ESP32 module with ESP32
Type "help()" for more information.
>>> %Run -c $EDITOR_CONTENT

  0
  0
  0
  0
  0
  0
  0
  65535
  65535
  65535
  65535
  65535
  65535
  65535
  0
  0
  0
  0
  0
  0
  0
```

Figure 25. Adjusting sleeping time to 0.5s

In this demonstration, 65535 indicates when the alarming system is triggered, while 0 indicates the alarming system in off-state. When sleeping time is kept as low as 0.1s, the microcontroller received more input from the motion sensor, which is very sensitive to the surrounding environment. Any small vibration can trigger the motion sensor and trigger the alarming system. Meanwhile, when sleeping time is adjusted to 0.5s, the less inputs from motion sensor allow small vibrations to be filtered out without triggering the alarming system.

VI. WINTER BREAK AND FIRST WEEK SCHEDULE

Task	Owner	Comments
Implement GSM function	Joey, Nguyen, Minh	GSM module has arrived! Over the break, we will study its operation
Research on power switch circuit (to add a back-up battery)	Joey, Nguyen, Minh	In case car battery die out or does not have enough capacity, the system need to switch to secondary power source.
Research on possible relay and order	Joey, Nguyen, Minh	This could be time consuming
Read the chosen Book	All	This could be time consuming
Research spatial constraints for desired vehicles	Ryan	Decide on scope of project by doing research on spatial constraints on targeted vehicles and how many we should focus on.
Create more accurate solidworks model	Ryan	If possible I would like to make a more accurate model based on real dimensions of cars.
Confirm thermal analyses with hand calculations	Ryan	My hand calculations and solidworks analyses were not matching up so I want to confirm these over break.

Figure 26. Assigned tasks over Winter Break

Task	Owner	Comments
Test equipments to make sure everything is functional	All	Equipments may not be used for long period, or they may not compatible with new set of hardware.
Integrate the GSM module into the electronic subsystem	EEs and CPE	This could take time.
Prepare material and equipment for manufacturing	Ryan	Get required materials that will be required to make the housing (Unless outsourced).
Set up new meeting schedule for Winter Quarter	All	This should be similar from the previous quarter.

Figure 27. Tasks for 1st Week of Winter Quarter

VII. REFERENCES

[1] Bender, Danny. "Diagnosing Starter Problems – How to Check, Test and Replace." *Danny's Engineportal*, 15 Nov. 2022, dannysengineportal.com/diagnosing-starter-problems-what-to-check-testing-and-replacement.

[2] *AAA Premium Battery*. www.napaonline.com/en/p/BAT8496RAAA?cid=paidsearch_shopping_dcoe_google&store=23429&campaign=GSC-Batteries&campaign_id=6478913224&adgroup_id=77736595836&adtype=pla&gclsrc=aw.ds&.