3. Design Approach

KidGuard is a child protection device equipped with weight sensors, thermal sensors, and a communication system to notify users if a child is left unattended in a car seat. KidGuard detects the child's presence with weight sensors and monitors the vehicle's interior temperature with thermal sensors. Subsequently, the long-range (LoRa) communication system receives the collected data. Afterward, the LoRa sends the information to the user.

KidGuard's critical constraints include a development cost of $1000, a completion deadline of December 2024, high-temperature endurance, and reliability. Furthermore, KidGuard abides by the Federal Motor Vehicle Safety Standard (FMVSS), Standard for a Smart Transducer Interface for Sensors and Actuator (LoRa Protocol), and Institute of Electrical and Electronics Engineers (IEEE) Standard for Information Technology.

3.1. Design Options

Several design options were considered for KidGuard. The three design options below describe the choices on KidGuard's design. The goal is to achieve accurate weight and thermal sensing while keeping the device away from children. Moreover, KidGuard must be reliable for the safety of the children.

A big obstacle for KidGuard is extreme heat inside the vehicle during hot weather. Team Guardians has selected Design Option 1 as the design approach because it handles this obstacle with better precision than the other options. Design Option 3 is the second-best fit compared to Design Option 2 since both can withstand a large amount of heat, with the only problem being the use of the car as a power supply.

3.1.1. Design Option 1

The chosen design situates KidGuard underneath the car seat to avoid contact with the child. The weight sensor attaches to the bottom of the car seat to detect the child. The thermal sensor is outside the bottom casing of the car seat to receive accurate temperature readings. Additionally, the power supply is detachable and rechargeable. KidGuard includes an enclosure made from high-temperature filaments to help mask extreme temperatures. The LoRa HAT communicates the readings to the user using a GUI.

An advantage to this design is that KidGuard sends up-to-date information from long distances directly to the user's smartphone. Furthermore, KidGuard can withstand extreme heat conditions in the car, which makes KidGuard more reliable. The only drawback to this design is that communicating with a GUI is challenging.

3.1.2. Design Option 2

The second design option entailed KidGuard communicating to the user through an alarm system. KidGuard sets off an alarm when the temperature is too hot or too cold. KidGuard is underneath the car seat, and the design remains similar to Design Option 1.

An advantage to this design is that KidGuard does not have to communicate long distances with the alarm in place, making the overall design easier. The main worry is the user is out of range of the device before it starts alerting. KidGuard would alert only when the conditions in the vehicle were no longer safe; by that point, the user might be in a store where it is impossible to hear. The user would have to rely on a bystander to find them and alert them that their alarm is going off. This design option was discarded since the alarm is not dependable.

3.1.3. Design Option 3

The third design option considered by KidGuard involved using the vehicle's car battery as a power source. KidGuard detects a child's presence in the car seat using load cell sensors. The ambient temperature is measured with a thermal sensor placed outside the KidGuard enclosure. The data collected with KidGuard is then relayed to the user with the LoRa communication device.

An advantage to using the vehicle's car battery is the risk of having the device run out of power is no longer a concern. However, this option has been discarded due to having a wire run throughout the vehicle's interior. Furthermore, this version's implementation presents several complications including inconvenience, unappealing aesthetics, and safety concerns for both child and user. A wire running throughout the vehicle could be easily accessible to a child and unplugged rendering the device powerless and risking electrical shock.

3.2. System Overview

KidGuard's black box runs with a power supply that takes in different inputs to transmit a notification to the user. A simplified diagram of how KidGuard works is shown in Figure 3-1.

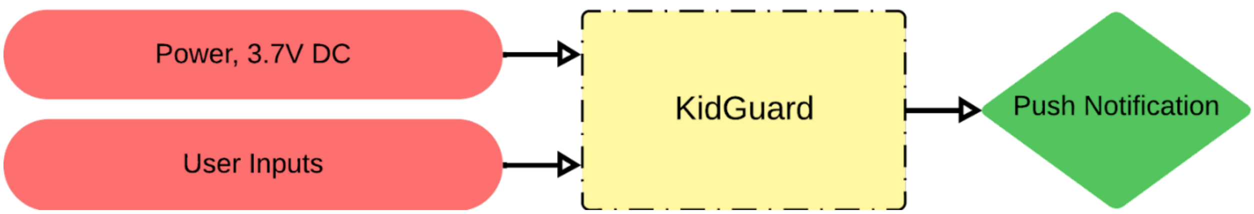

Fig. 3-1 KidGuard Functionality Overview (Level 0)

KidGuard features numerous components to transform raw inputs into push notifications displayed to the user. Figure 3-2 provides an in-depth representation of the device.

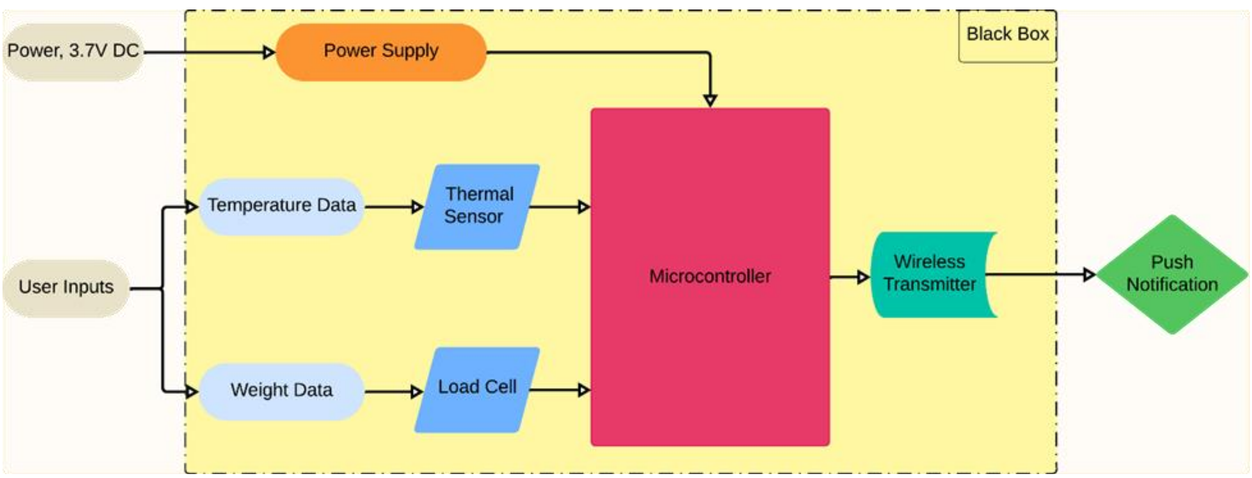

Fig. 3-2 KidGuard Functionality (Level 1)

Inside KidGuard's black box, load cells detect a child's presence. The thermal sensor identifies dangerous high and low temperatures. The microcontroller, powered by a DC supply, processes incoming data. Subsequently, the wireless transmitter sends a push notification to the user.

3.2.1. Microcontroller

KidGuard chose the Raspberry Pi 4 Model B for its Wi-Fi capability and accessibility, which makes it the best choice for KidGuard. This microprocessor takes input from the temperature sensor, weight detection, and LoRa HAT. Using the terminal, KidGuard interacts with all subsystems by matching the pin layouts with the pin initialization in the code. Table 3-1 illustrates the various microcontrollers that were considered.

Table 3-1: Microcontroller Comparison

Processor	Bluetooth	Dimensions (mm)	Operating Temperature	RAM	Price
Requirements	Yes	Max. 100 x 100	32 to 122°F (0 to 50°C)	4 GB	≤$100
Raspberry Pi 4 Model B [2]	Yes	95.3 x 70.1	32 to 185°F (0 to 85°C) [2]	4 GB	$61.75
Raspberry Pi 5 [3]	Yes	86 x 56	32 to 185°F (0 to 85°C) [2]	4 GB	$74.59
Arduino Uno [4]	No	68.6 x 53.4	-40 to 185°F (40 to 85°C) [5]	32 KB	$27.60

The Raspberry Pi 4 Model B was chosen for KidGuard due to its cost-effectiveness, ample heat tolerance, and adequate size. Meanwhile, the Raspberry Pi 5's improved 40-50% computational power and sustained performance exceed KidGuard's application.

The micro-HDMI ports are used to interact with the Raspberry Pi 4B's terminal on a separate monitor. The USB-C port is used to power the Raspberry Pi 4B, but the final design uses the Raspberry Pi Juice Platform, which is rechargeable and portable. Figure 3-3 depicts the microcontroller.

Fig. 3-3 Raspberry Pi 4 Model B [1]

Team Guardians acquired heatsinks that are situated on top of the Central Processing Unit (CPU), Random Access Memory (RAM), and the USB controller chip. The heatsinks protect the Raspberry Pi 4B from overheating and damaging the CPU, RAM, and USB. Additionally, Team Guardians purchased a miniature fan that mounts on the enclosure to help circulate the air inside.

3.3. Subsystems

KidGuard's prototype design includes the following four subsystems:

1. The first subsystem is Bluetooth and LoRa, these communicate between the LoRa and Raspberry Pi 4B to send data to the user.
2. The second subsystem communicates with a GUI.
3. The third subsystem is the thermal sensor for high-temperature detection.
4. The fourth subsystem is weight detection for any pressure exerted in the seat to activate the device.

These four subsystems work together to send accurate and reliable data to the user.

3.3.1. Bluetooth and LoRa

For the Bluetooth and LoRa subsystem, KidGuard requires a method to transmit data to any smartphone. The team opted to use wireless transmitters to send various health-related information. The LoRa HAT sits on top of the Raspberry Pi 4B with the antenna pointing outside of the seat for the best range detection.

The communication system is one of the most important subsystems because an accurate, up-to-date notification is required to ensure the safety of the child inside of the car. Long-range communication is a key selling point for KidGuard, so this feature is crucial. Table 3-2 lists the component specifications of wireless transmitters.

Table 3-2: Bluetooth and LoRa Comparison

Model	Range (m)	Dimensions (mm)	Operating Temperature	Price
Requirements	≥ 1000	Max. 70 x 50	32 to 122°F (0 to 50°C)	≤ $100
SX1262 LoRa HAT [6]	5000	65 x 30.5	-40 to 185°F (-40 to 85°C)	$33.50
Sixfab LTE-M [7]	1000	57 x 65	-13 to 158°F (-25 to 70°C)	$90
Bluetooth Module HC-06 [8]	10	36 x 15	23 to 149°F (-5 to 65°C) [9]	$8.95

The Bluetooth Module HC-06 and Sixfab LTE-M do not meet the range standards that KidGuard requires, which is an enormous drawback. Furthermore, the operating temperature for both devices is approximately 30°F lower than the maximum operating temperature of the SX1262 LoRa HAT.

Thus, the SX1262 LoRa HAT was chosen for its ability to communicate long distances from the vehicle to the user. LoRa also can withstand the highest temperature of the transmitters considered. The price is reasonable for KidGuard. Figure 3-4 depicts an image of SX1262 LoRa HAT.

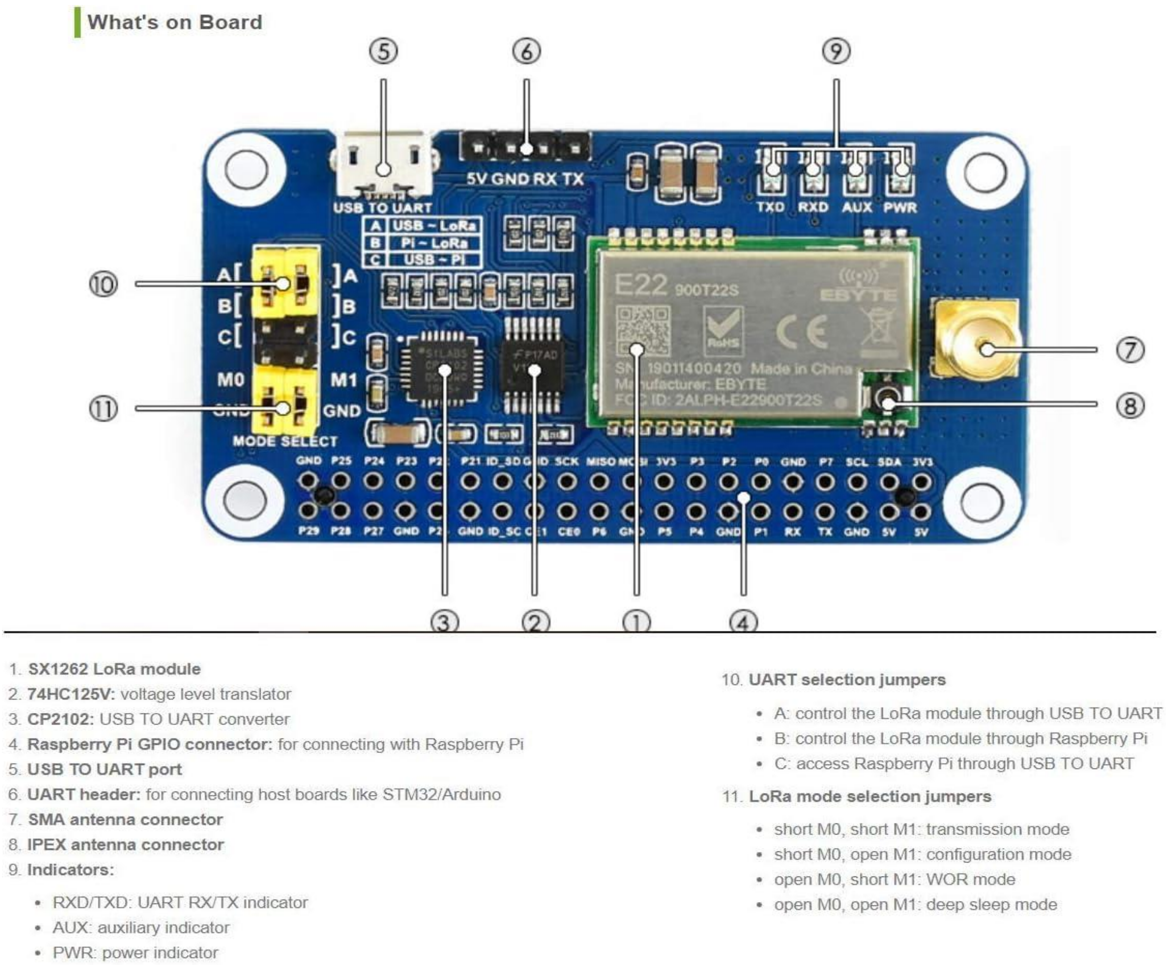

Fig. 3-4 SX1262 LoRa HAT [6]

The antenna located at point 7 facilitates communication for the SX1262 LoRa HAT over 5000 m [6]. The SX1262 LoRa HAT can achieve longer communication distances, higher rates, lower power consumption, better safety, and anti-interference even in challenging environments for it to communicate. As the sensors collect data, SX1262 LoRa HAT transmits the temperature and weight data to the user in our next subsystem.

3.3.2. Graphical User Interface (GUI)

The Raspberry Pi 4B built-in Bluetooth capability, depicted in Figure 3-5, is selected for its resistance to high temperatures and compatibility. The module connects to the cellular device through the network and transmits notifications.

The GUI monitors and displays the collected data. Figure 3-5 illustrates four separate scenarios of how KidGuard interacts with the user’s handheld device when certain conditions are met, one of the different scenario messages can show up on the person's cellular device.

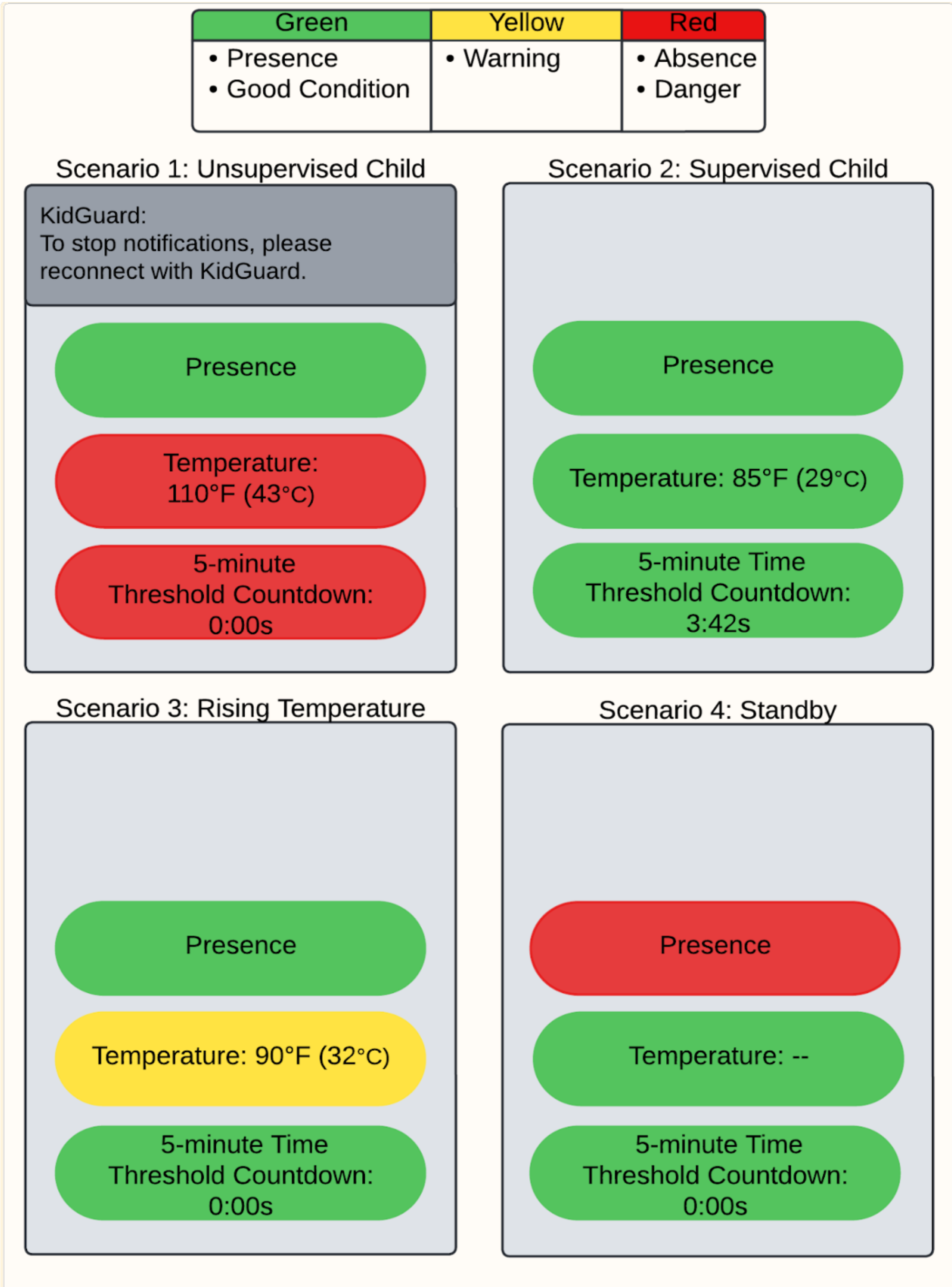

Fig. 3-5 GUI Mockup

The front-end aspect of the GUI is created with HTML and CSS. Additionally, it features pressable buttons that change color between green, yellow, and red. The back-end aspect feeds the data in and changes the button's color. Furthermore, the phone is notified once the parent is out of range or disconnected.

3.3.3. Temperature

For the temperature subsystem, a thermal sensor is used to detect the temperature inside of the vehicle. The data informs the user of harmful temperatures to the child. KidGuard's utmost purpose is to limit the number of heat stroke-related deaths of children inside a hot vehicle. The temperature sensor KidGuard decided on is the SparkFun High Precision Temperature Sensor TMP117 (TMP117). Table 3-3 lists the component specifications of thermal sensors.

Table 3-3: Thermal Sensor Comparison

Model	Thermometry	Dimensions (mm)	Operating Temperature	Price
Requirements	>100°F (>37.78°C)	Max. 100 x 100 x 100	32 to 122°F (0 to 50°C)	≤$100
SparkFun High Precision Temperature Sensor - TMP117 [10]	-67 to 302°F (-55 to 150°C)	76.2 x 50.8 x 25.4	-67 to 302°F (-55 to 150°C) [11]	$14.95
Raspberry Pi Sense HAT [12]	32 to 149°F (0 to 65°C)	29.97 x 73.91 x 100.08	32 to 122°F (0 to 50°C) [13]	$49.45
Gikfun DS18B20 [14]	14 to 185°F (-10 to 85°C)	147.3 x 15.2 x 99.1	-67 to 257°F (-55 to 125°C)	$11.58

In Figure 3-6, the SparkFun High Precision Temperature Sensor is displayed below. Team Guardians utilizes the TMP117 for its high-temperature measurement capability (thermometry) and operating temperature range. KidGuard compared the TMP117 to the Raspberry Pi Sense HAT (Sense HAT) as well as the Gikfun DS18B20 (Gikfun).

The Sense HAT's operating temperature range is inadequate, risking malfunction in high temperatures equal to and above 122°F (50°C), which is often reached in the vehicle's interior during summer. The Gikfun surpasses the Sense HAT's operating temperature range but cannot match the breadth of the TMP117.

Although the Gikfun's operating temperature is near the TMP117, its application is primarily designed for food and beverage as opposed to an ambient temperature thermometer. For these reasons, Team Guardians decided on the TMP117, as shown in Figure 3-6.

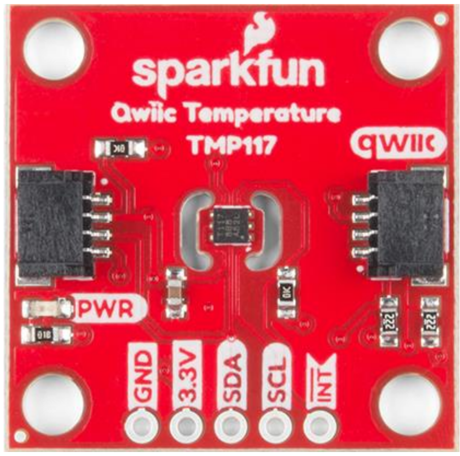

Fig. 3-6 SparkFun High Precision Temperature Sensor - TMP117 [10]

The temperature sensor on KidGuard keeps reading data for the Raspberry Pi 4B to keep up-to-date temperatures every second when it is not in standby mode. Until then, pressure must be applied to the seat, activating the weight detection subsystem.

3.3.4. Weight Detection

KidGuard currently uses a Dorhea load cell, but in the final design, KidGuard intends to use the Uxcell as it has a higher temperature resistance. The weight detection subsystem ensures the child is in the car seat before picking up temperature readings. This feature prevents the user from getting unnecessary temperature readings if the child is not in the vehicle.

The weight detection subsystem activates the device if more than 2.2 lbs (1kg) pressure is applied. If the optimal pressure is applied, the seat activates to start all subsystems and leave standby mode. Table 3-3 lists the component specifications of load cells.

Table 3-4: Load Cell Comparison

Model	Weight Range	Dimensions (mm)	Operating Temperature	Price
Requirements	0 to 100 lbs (0 to 45 kg)	Max. 45 x 45	32 to 122°F (0 to 50°C)	≤$50
Dorhea [15]	0 to 110 lbs (0 to 50 kg)	34 x 34 [16]	32 to 122°F (0 to 50°C)	$9.99
Uxcell [17]	0 to 220 lbs (0 to 100 kg)	42 x 38	-4 to 149°F (-20 to 65°C)	$10.09
FX292X-100A [18]	10 to 110 lbs (4.54 to 49.9 kg)	10.5 (Diameter)	32 to 185°F (0 to 85°C)	$34.68

Team Guardians chose the Uxcell load sensor for its high-weight detection range and high heat resistance. The Uxcell's rectangular flat design allows it to fit comfortably underneath the padding of a car seat. In Figure 3-7, the Uxcell The following text is displayed. The FX29X offers an acceptable temperature range, however, the minimum activation weight does not allow premature children or newborns to be detected.

The physical structure of the FX29X is taller than the other options listed. This leads to a problem of comfortability as the load cell is beneath the padding of the car seat. The Uxcell is more effective at weight sensing and weight exceeding 220 lbs.

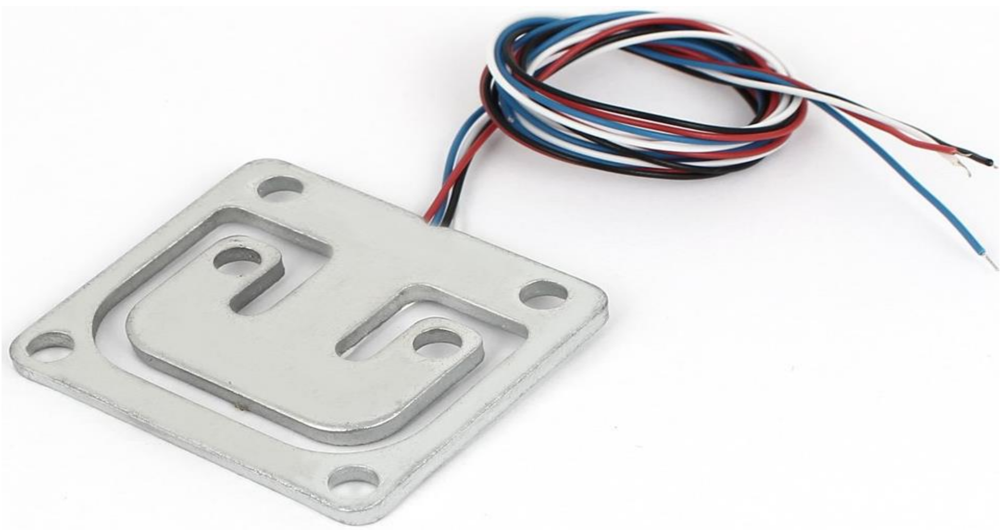

Fig. 3-7 Uxcell Load Cell [17]

In the output code for Dorhea, Linux has a time sensitivity issue that causes random values to appear when reading the weight. The Dorea influenced the team's decision to switch to Uxcell. The two products are similar in size comparison and do not affect the enclosure size.

3.4. Level 2 Prototype Design

The completed KidGuard prototype consists of a fully functioning GUI that can accurately relay data from KidGuard to the user. The GUI sends push notifications and displays information gathered by the peripheral sensors. KidGuard's microcontroller is in a 3D-printed box stored in the undercarriage of the car seat. KidGuard has sufficient power to stay active for 4 to 6 hours and in standby mode for 24 hours.

KidGuard runs on Python to operate each subsystem. Python includes all necessary libraries for the thermal sensors, load cells, and the LoRa HAT. Additionally, the information that is processed by Raspberry Pi 4B is sent to a web app hosted by Netlify. Handheld devices can use the web app by saving onto and accessing through the home screen.

3.4.1. Level 2 Diagram

KidGuard's final prototype design is shown in Figure 3-8. The enclosure contains the Raspberry Pi 4B, PiJuice Power Platform power source, TMP117, and Uxcell load cells. Additionally, the enclosure features sufficient air circulation. Otherwise, the design resembles Figure 3-2.

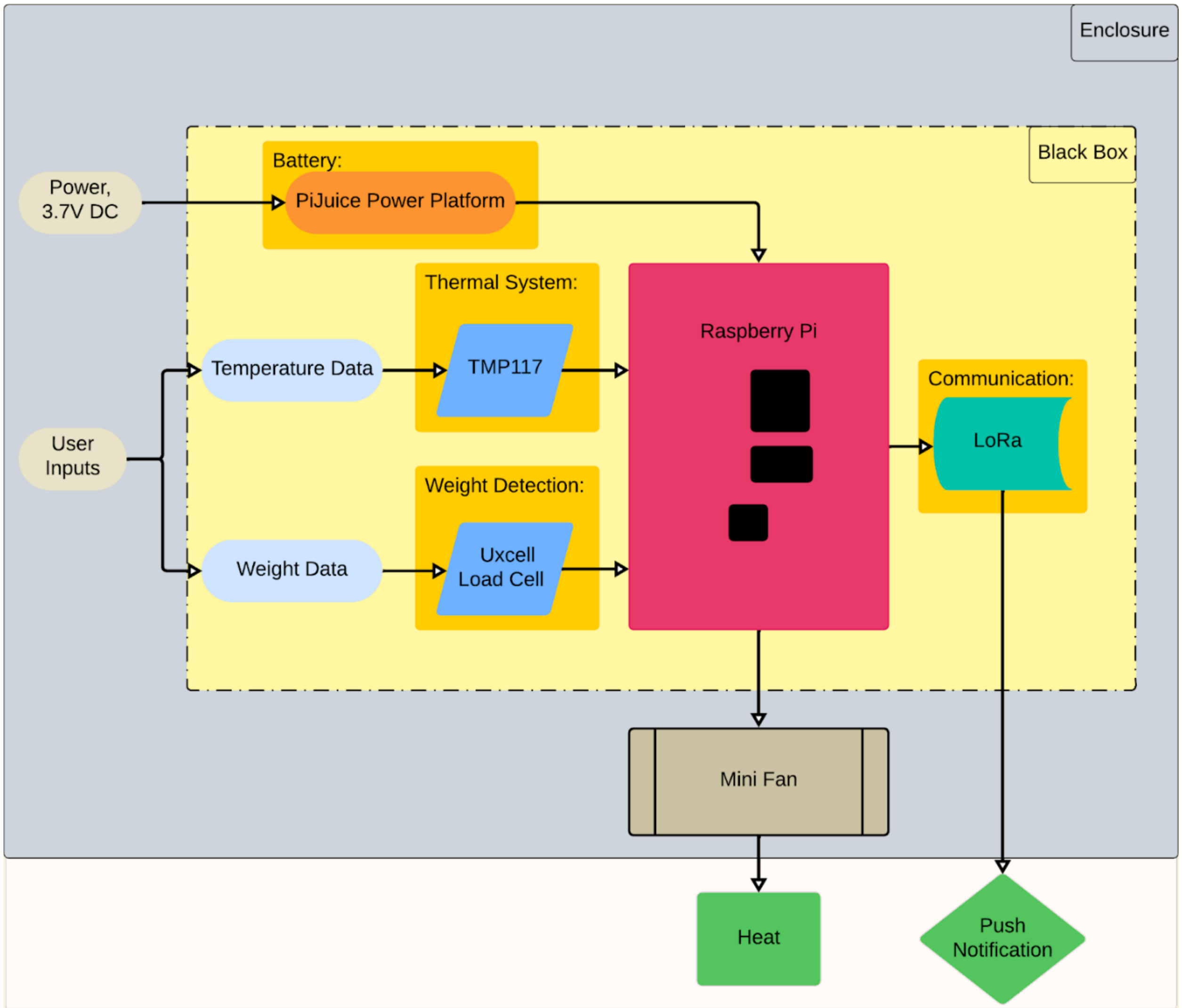

Fig. 3-8 Diagram for KidGuard (Level 2)

The PiJuice Power Platform sits on top of the Raspberry Pi 4B. However, this configuration increases heat generation, causing the CPU temperature to rise. Once the temperature reaches 60°C (140°F), the CPU struggles to maintain constant computational speed, impacting the computer's performance. To address this complication, heatsinks, depicted in black in Figure 3–8, are mounted with adhesive glue to dissipate heat passively from the appropriate components.

Additionally, fans, displayed in brown in Figure 3-8, are installed onto the enclosure to expel heat out of the enclosure. Despite these measures, an alternative approach involves running wires through each component to connect the PiJuice Power Platform to the Raspberry Pi 4B. KidGuard's components are mounted on the Raspberry Pi 4B but are operational without being attached.

The sections above accurately describe Team Guardians' product approach. Each section meticulously describes the functional operation of the subsystems and their components. The next portion discusses testing procedures, results, and troubleshooting.

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