Park Pal: A Novel Parking Guidance System

Steve Joshua, Maria Mathai, Leo Mendoza

Department of Electrical & Computer Engineering, University of Waterloo

ECE 198: Project Studio

Mr. David Lau, Ms. Shadi Vandvajdi

October 30, 2024

Table of Contents

Needs Assessment

Client/Customer Definition

Key Client Characteristics:

- Geographic: Residents of the City of Waterloo
- Demographic: Owners of single-occupancy vehicles
- Demographic: Those who commute to work by driving

The client for this project is defined as the residents of the City of Waterloo who drive single-occupancy vehicles to work. As per data from the 2021 City of Waterloo Census, the City of Waterloo has a population of 121,436. Out of the general population, 76.4% of residents report commuting to work by driving [1]. This determines a client size of about 92,777, placing the client within the required scope of this project.

Client Challenges

The client, commuting drivers in the City of Waterloo, have to deal with bad parking and the varying issues that come with it. Prominent issues include increased collision risk, parking space wastage, and the effects of searching for parking.

Research shows that in Canada, 10% of all car collisions occur in parking lots [2]. Collisions can have a myriad of repercussions, including health and financial damages. After car collisions, emergency room victims frequently suffer neck, abdominal, and lower limb injuries [3]. However, car collisions have long-term health impacts too: 45% of traffic collision victims experience related pain two years post-collision [4]. Factoring in social costs, deaths, injuries, and property damages, car collisions have cost Canadians an estimated $246.1 billion over ten years [5].

Illegal parking is also associated with traffic congestion and parking space wastage, increasing travel time and resulting in lost productivity [6]. Congestion lowers Canadians' quality of life: according to a CBC survey in the GTA, half of all respondents say they avoid shopping, entertainment or sports games because of congestion [7].

The action of searching for parking itself is a challenge. Wasted parking space related to bad parking can lead to extra carbon dioxide emissions, wasted fuel, and idle time. For example, every year in Los Angeles, the whole city wastes nearly 1.61 million kilometres of low-speed vehicles, wastes 95,000 h, consumes 47,000 gallons of fuel, and emits 730 tons of CO_2 emissions [8]. This has greater impacts, not only on individual citizens but also on the greater climate and planet. According to the European Environment Agency, 60.6% of carbon emissions in the EU are produced by cars [9].

Competitive Landscape

- Parking tickets
  - Parking tickets work by issuing punitive action and generating revenue. By issuing a fine, parking tickets serve as a financial consequence for drivers who park illegally or irresponsibly. The threat of a fine encourages drivers to be more cautious and considerate about where and how they park. Fines collected from parking tickets also go towards maintaining city infrastructure, including parking infrastructure. However, in practice, parking tickets fall short. Recently, cities across Canada have increasingly been forgiving millions of dollars on parking tickets [10, 11, 12]. Additionally, according to Toronto Police Service statistics, fewer parking tickets have been issued post-pandemic [13]. Tickets have proved insufficient as a method of deterring bad parking.

- Parking borders in parking lots:
  - Painted borders in parking lots are designed to organize vehicles in public spaces and guide drivers to park within designated spaces. Often painted with bright colours, they are intended to provide visual cues for where cars should be positioned relative to other cars, and act as even spaces for cars to park inside. However, paint can easily weather and chip, especially under the pressure of thousands of cars, affecting their visibility and effectiveness [14, 15]. Without consistent maintenance to ensure visible parking borders, drivers can quickly struggle to park correctly, making parking borders insufficient.

- Park Assist Systems
  - A park assist system is a system within a car that uses sensors and cameras to help drivers park their vehicles. When activated, it scans for available parking spaces and calculates the best path to park. The system provides visual and auditory guidance, allowing the driver to control acceleration and braking while it steers. In fully autonomous versions, the vehicle can park itself, adjusting to avoid obstacles [16]. Unfortunately, parking assist systems exist only in more recent car systems, so this method of parking control is inaccessible to many drivers, and remains insufficient as a method of parking control.

Requirement Specification

Functional

1. **Lights**: The product will use a matrix of LEDs to alert the driver of parking errors. Lights have been proven to improve the visibility of signs, such as stop signs, and improve driver adherence [17]. Within ParkPal, the light emitted from the LEDs is essential for effective communication between the device and the driver, acting as a key visual cue to convey the direction the driver should reposition to. When a parking error is detected, the LEDs provide an alert to the driver, indicating two things. Firstly, that they have parked incorrectly, and that the car should be repositioned. Secondly, it communicates guidance on the necessary corrective movements to the driver, such as whether the vehicle should be repositioned forward, backward, or sideways. This feedback ensures the driver understands the exact direction in which they must adjust to achieve proper parking alignment, improving clarity.
2. **Sound**: The product will use buzzers to alert the driver when they have made parking errors. This has been proven effective by research into railroad-grade crossing devices, such as sound, which have been proven to improve driver awareness and safety [18]. Within Park Pal, the sound from the buzzers act as a supplement to the visual indicator lights. They alert the driver, firstly, that an incorrect parking orientation has been taken, and secondly, that the lights are indicating the direction to move towards. This aids the human driver in correcting the parking.
3. **Parking spot distance**: The product will use ultrasonic sensors to ensure cars do not park outside of the parking spot. This is because one of the most common parking lot accidents is incidents where cars pull out of tight parking spaces and scrape other cars [19]. These accidents can be minimized by ensuring each car remains within its bounds. Within the context of Park Pal, this is addressed by the usage of ultrasonic sensors to measure the distance the vehicle is from the parking bounds. The various sets of distance data measured and collected by the ultrasonic sensors is necessary for the system to determine if the vehicle exceeds the bounds of the parking space. This then leads to the operation of the conditional logic that allows the lights and sound systems to activate accordingly to communicate the errors in the driver's parking to the driver. Once the driver interprets these warnings, the necessary corrective parking action should occur.
4. **Guidance system:** The product must be able to display arrows directing the driver in the correct direction to park. The province of Ontario has already implemented the usage of arrows in traffic lights, making it easy for drivers to understand [20]. The usage of these arrows is integral to the communication component of this project. Within Park Pal, the arrows will be displayed on the green LED matrices. As these green arrows are already familiar as symbols of driving direction to drivers within the client space, they will be intuitive to drivers and better facilitate communication. The design of Park Pal relies on the arrows communicating the correct orientation to drive in.

Technical

1. **Light colour** (nm): The LED arrays will display the symbols in green light. Green is the most visible colour to the human eye, making the symbols more visible to drivers. We specifically aim to have the light emit a wavelength between 550-555 nm [21]. This wavelength is beneficial for the purpose of Park Pal, as the green LEDs will be most visible, eye-catching, and accessible to all drivers. This ensures that Park Pal can be used by the widest variety of drivers, including those with visual impairments or those driving at night, and will be maximally effective.
2. **Frequency** (kHz): The product will use two Piezoelectric buzzers, which have a recommended usage frequency between 1-10 kHz [22]. However, research in music production indicates the most tiring frequency range for the human ear is 0.5-2 kHz [23]. The buzzer will emit a frequency of 1 kHz, which is the most efficient and effective. Within the context of Park Pal, this proves effective, because this frequency will catch the driver's awareness when they have left the boundaries of the parking space. This will alert and help the driver recognize they must reposition the parked car.
3. **Distance** (cm): For maximum accuracy, the ultrasonic sensors have an accuracy of ± 0.3 cm, so drivers will have to park within 0.3 cm of the parking borders [24]. The distance measurement is crucial to Park Pal’s operation. The distance measurement determines if the driver has gone beyond the boundaries of the parking space. If the sensor detects that the vehicle is within a certain distance from the sensor (ie. exceeded the boundaries), then the sensor will convey to the rest of the system that there is an object exceeding the parking boundary threshold, which the system can then interpret and communicate to the driver.
4. **Delayed guidance** (s): The product will give the driver a delayed grace period between 0-5 seconds to adjust their parking on their own before the alarm system activates. The product aims to reduce collisions in parking lots; however, sudden distractions are a leading cause of vehicular collisions, which is counterintuitive [25]. This is integral to Park Pal’s operation, as one of the problems it aims to remedy is the rate of vehicular parking lot collisions. By providing a grace period, the system offers a gentler approach that reduces the likelihood of startling or causing unnecessary distractions for the driver, decreasing the risk of parking lot collisions. The 0-5 second delay allows the driver time to adjust their parking without immediate pressure from the alarm, promoting safer and smoother parking adjustments.

Analysis

Design

Park Pal will use three ultrasonic sensors, two green LED matrices, two piezoelectric buzzers, and a stand. The design is based on the required size of a parking space in the City of Toronto [26]. The product also uses two STM32F401RE microcontrollers programmed in C++. One microcontroller processes sensor input and transmits data to the other, which provides visual and auditory feedback for users to reposition their cars. This setup ensures instant feedback to the driver by facilitating communication between the user, sensors, and alert systems.

The input circuit will consist of one STM32401RE connected to three HC-SR04 ultrasonic sensors. One of the sensors, facing either the front or back of the vehicle, will be placed at a distance of <x> m away from the middle of the parking block. Then, there will be one sensor, facing the side of the vehicle, placed at a distance of <y> m away from the middle of each parking line. Positioned at these fixed locations, the three sensors will constantly measure their distance from the vehicle’s front/back (end) and sides, incorporating the distance separating the sensors from the parking block and lines to calculate the distance between the vehicle and the boundaries of the parking space. This set of distance data will then be sent to the output circuit.

The output circuit will consist of one STM32F401RE connected to two green LED matrices and two piezoelectric buzzers. Using the stream of distance data from the input circuit, the microcontroller will constantly apply conditional logic to determine if the vehicle is within the parking space boundaries and, if not, determine the corrective movement required based on the vehicle’s lateral and longitudinal positioning, then prompt the LEDs and buzzers to activate accordingly. Note that Park Pal will prioritize providing feedback for lateral alignment because once the vehicle is laterally aligned but not longitudinally aligned, it is easier to pull in or out than to adjust left and right if the situation is the opposite. That is, the device will not provide longitudinal corrective guidance for the user until they correct their lateral alignment.

When there is no corrective movement necessary, the two LED matrices and two buzzers will not be turned on. If the side of the vehicle crosses the left parking line, the right LED will blink and the right buzzer will pulse. Conversely, if the side of the vehicle crosses the right parking line, the left LED will blink and the left buzzer will pulse. After the vehicle’s lateral alignment is corrected, Park Pal will check for its longitudinal positioning. If the end of the vehicle crosses the parking block, both LEDs will blink and the two buzzers will pulse alternately. Meanwhile, if the end of the vehicle is not within the proper pull-in depth threshold (too far out of the parking space), both LEDs will be constantly turned on and the buzzers will pulse in a staggered pattern.

Physical Schematic

Figure 1: *A birds-eye-view of Park Pal's physical setup.*

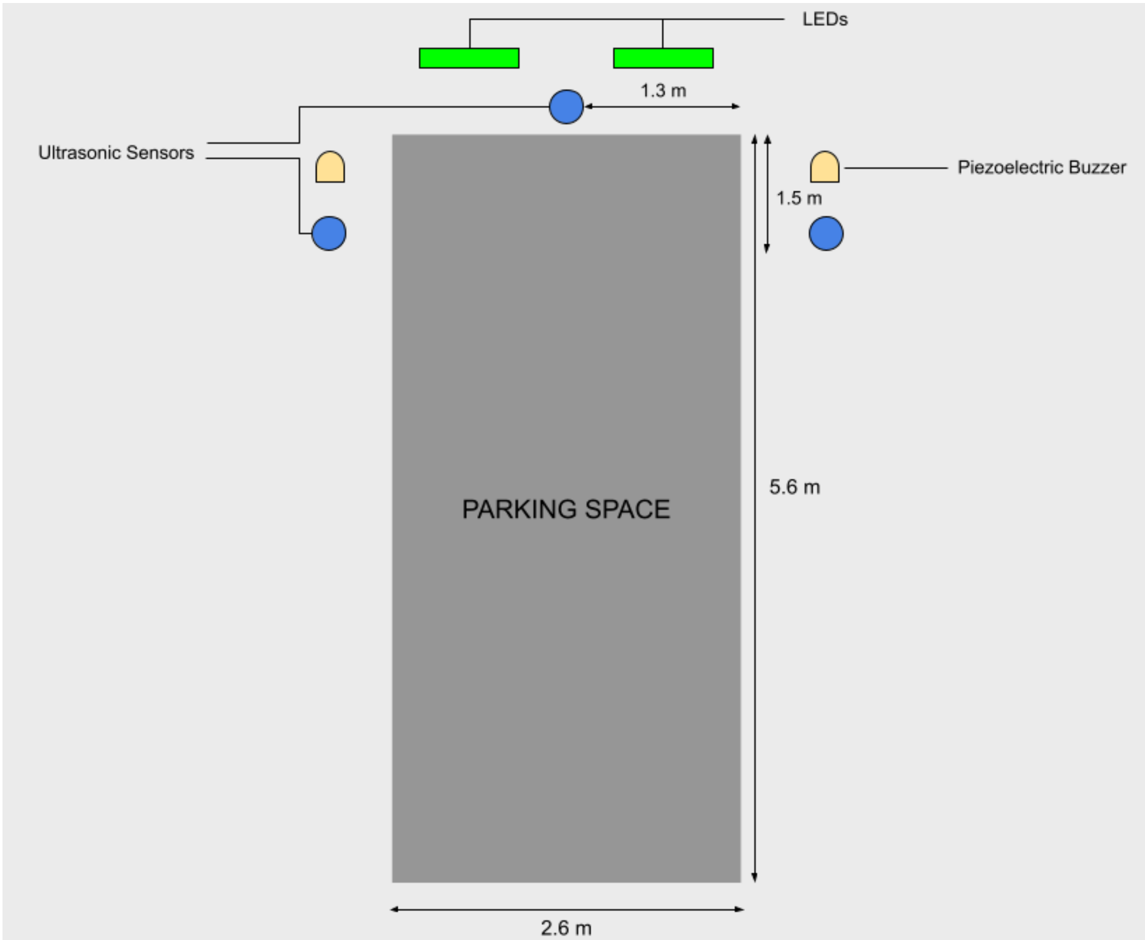
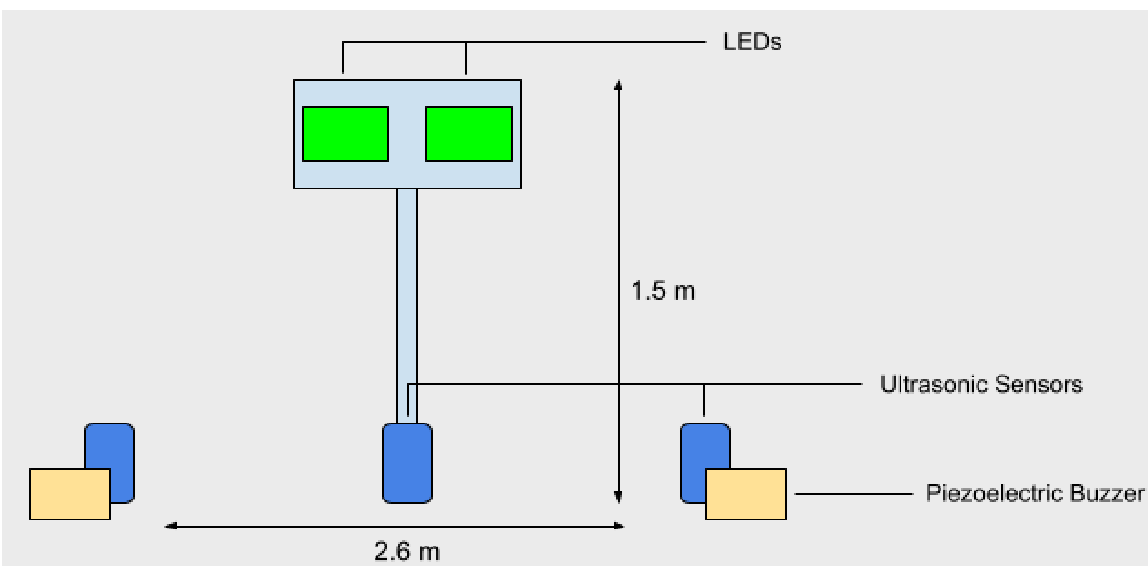


Figure 2: *A frontal view of Park Pal's setup.*



Circuit Schematic

Figure 3: *Wiring layout of Park Pal's input and output system components.*

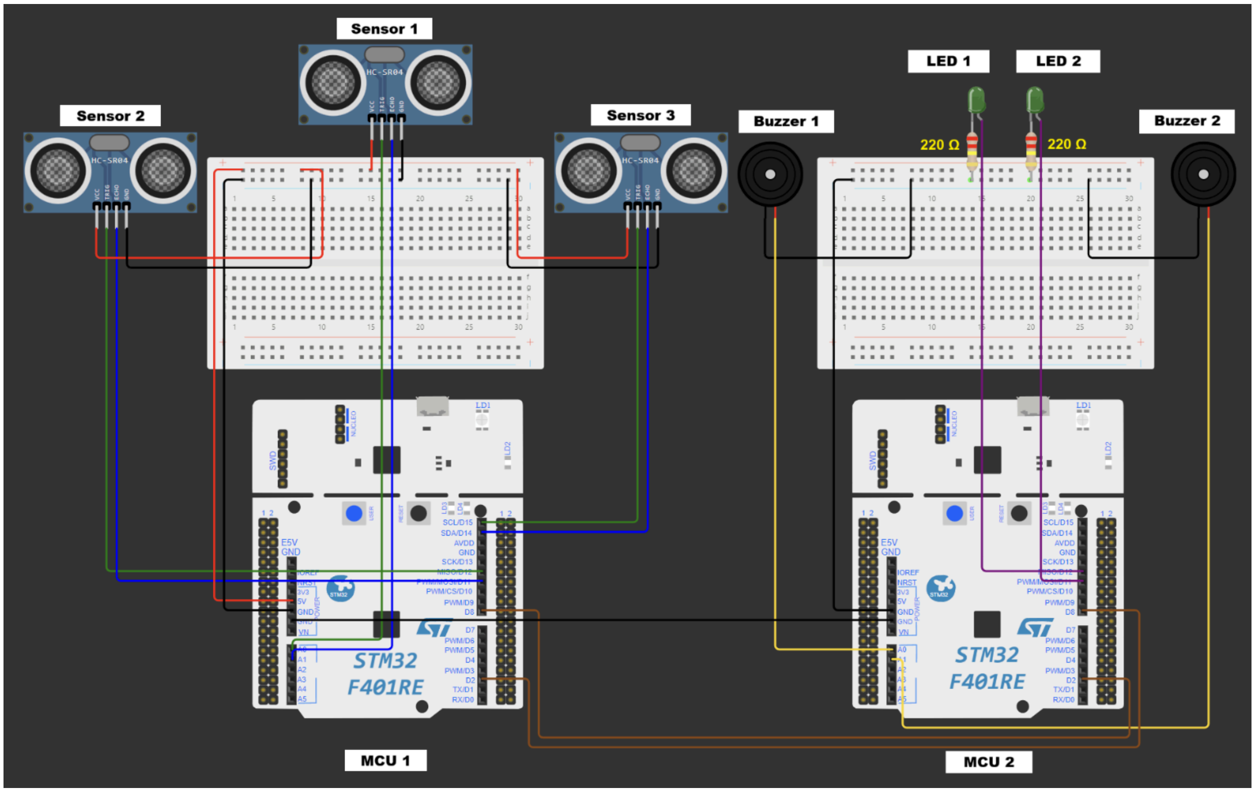


Figure 4: *Table of pin connections to the input circuit's microcontroller unit (MCU 1).*

On-board Label	D8	D2	A0	A1	D12	D11	D15	D14
Port-Pin Label	PA9	PA10	PA0	PA1	PA6	PA7	PB8	PB9
Connection	MCU 2 RX	MCU 2 TX	Sensor 3 TRIG	Sensor 3 ECHO	Sensor 1 TRIG	Sensor 1 ECHO	Sensor 2 TRIG	Sensor 2 ECHO

Note that the 5V and GND pins are connected to the power and ground rails of the breadboard, respectively, which the VCC and GND pins of the sensors are also connected to, thus allowing the three sensors to receive a supply of voltage. As well, to facilitate the UART connection between the two MCUs, MCU 1's GND pin must be connected to MCU 2's GND pin.

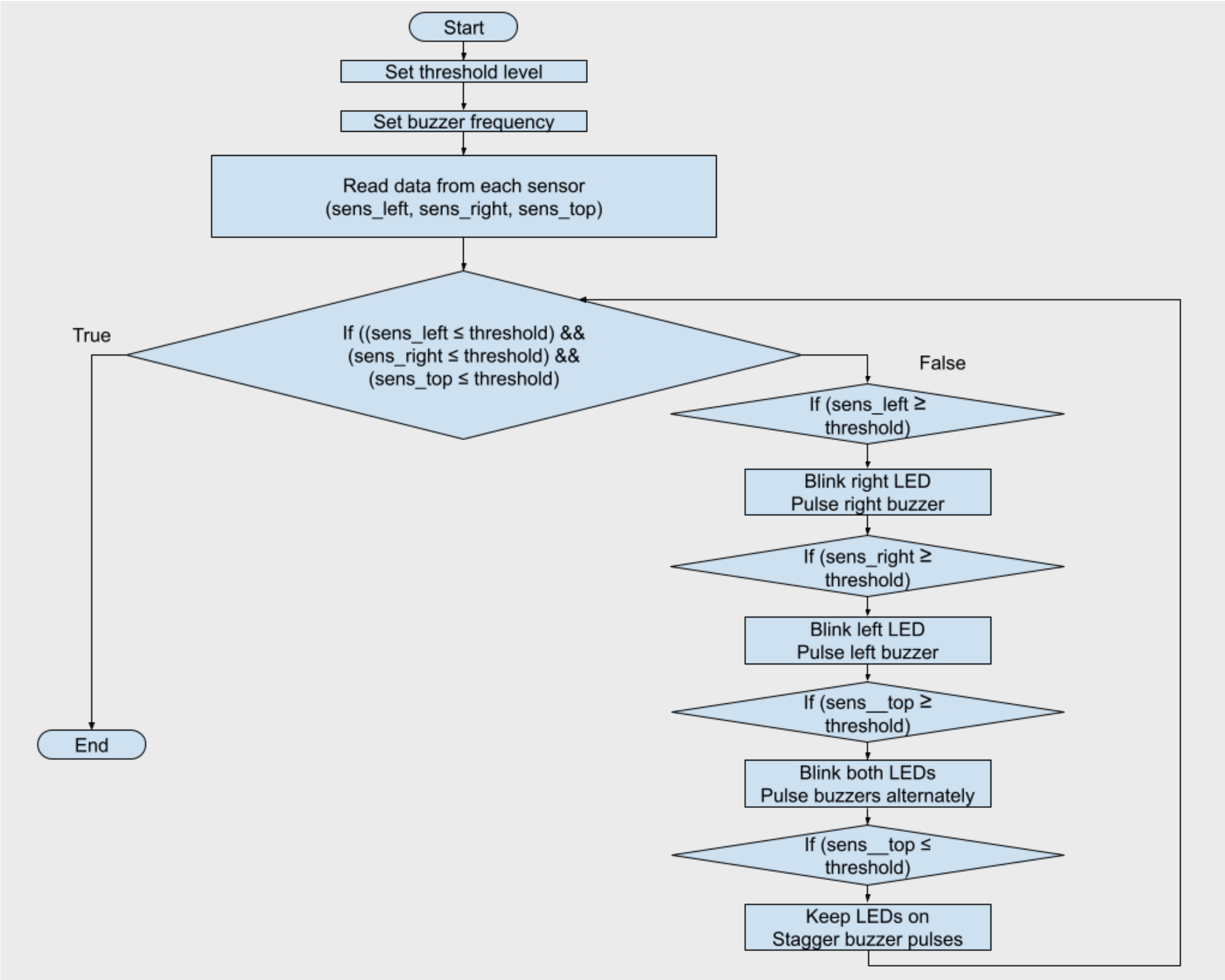
Figure 5: *Table of pin connections to the output circuit's microcontroller unit (MCU 2).*

On-board Label	D8	D2	A0	A1	D12	D11
Port-Pin Label	PA9	PA10	PA0	PA1	PA6	PA7
Connection	MCU 1 RX	MCU 1 TX	Buzzer 1 ANODE	Buzzer 2 ANODE	LED 1 ANODE	LED 2 ANODE

Note that the GND pin is connected to the ground rail of the breadboard, which the cathodes of the LED matrices and buzzers are also connected to, thus allowing the four components to close the circuit.

Code Flowchart

Figure 6: *Flowchart skeleton of Park Pal's code*



Design Alternatives

We used a computational decision matrix to weigh the advantages and disadvantages of the design alternative against each other. The alternatives vary mostly in the implementation of the input sensor system that detects the proximity of the vehicle in relation to the parking spot.

Alternatives

1. **Mobile on-vehicle sensors**: Mount infrared sensors directly on bumpers and sides to continuously scan the ground and detect parking lines
2. **Stationary sensors around parking space**: Strategically position ultrasonic sensors in fixed locations around the perimeter of a parking space
3. **Overhead sensors above parking space**: Attach an array of sensors on the ceiling or an overhanging frame to detect the vehicle from a top-down view
4. **Ground-level sensors on parking lines**: Embed sensors on the ground along the parking lines to detect the vehicle with LEDs acting like an airplane runway

Each objective is assigned a weight according to its relative importance. The scores under each alternative indicate how weakly or strongly the design meets the associated objective, with each score measured on a scale from 0 to 5.

Objectives:

1. **Cost-effectiveness**: Evaluate financial viability considering the $50 budget
2. **Ease of installation**: Assess simplicity, tools and time required to set up
3. **Accuracy of distance data**: Measure reliability of maneuvering guidance
4. **Real-time feedback quality**: Rate the immediacy and clarity of audiovisual cues
5. **Intuitive user interface**: Judge how user-friendly it is to interact with the device

Objectives	Weight	[A1]	[A2]	[A3]	[A4]
[O1]	10%	1	<u>4</u>	2	3
[O2]	25%	1	<u>5</u>	2	3
[O3]	20%	<u>5</u>	3	3	<u>5</u>
[O4]	20%	<u>5</u>	4	3	<u>5</u>
[O5]	25%	2	<u>5</u>	1	4
Sum	100%	2.85	**4.30**	2.15	4.05

Objectively informed by the computational decision matrix, we have chosen to implement design [A2], stationary sensors around the parking space, because it ranks the highest in [O1], cost-effectiveness, and the two most heavily weighted, [O2], ease of installation and intuitive user interface, and [O5], intuitive user interface.

Scientific and Mathematical Principles

1. **Kinematics**: Ultrasonic Sensors

Ultrasonic sensors use sound waves to measure distances. They emit a sound pulse and calculate the time it takes for the pulse-echo to return after bouncing off an object [27]. With the time taken for the wave to return and the speed of the wave, it is possible to calculate the distance between the ultrasonic sensor and the object, using the kinematic formula below.

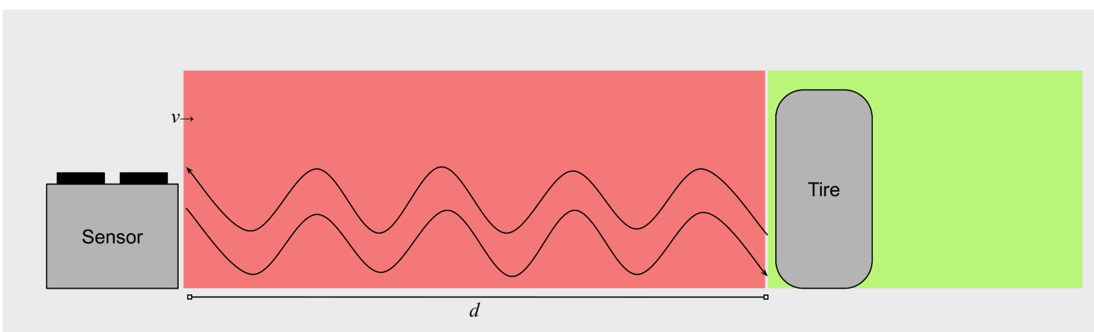
$$d = \frac{vt}{2}$$

Where:

- v is the speed of the sound wave in the air (343 m/s) [28]
- d is the distance from the sensor to the car
- t is the time taken for the pulse to return to the sensor

The ultrasonic sensor will emit a sound pulse, which will hit the tire of the car, and return to the sensor. The sensor will record the time it takes to hit the tire and travel back. Then, the distance the car is from the sensor can be determined, and further corrective instruction can be provided based on the data, if necessary.

Figure 7: *a representation of the integration of the ultrasonic sensor with the design. The green area represents the ideal distance from the sensor; the red area represents a distance too close to the sensor.*



2. **Conditional Statements**: Software Conditions

In order for the LED light array to effectively communicate with the driver, it must display the appropriate symbol. Our product will require the use of conditional statements within the product software [29]. On a basic level, some of our code will resemble the following sample:

```
if (sensorLeft > threshold) {
   displayArrow("right");
} else if (sensorRight > threshold) {
   displayArrow("left");
}
```

Where:

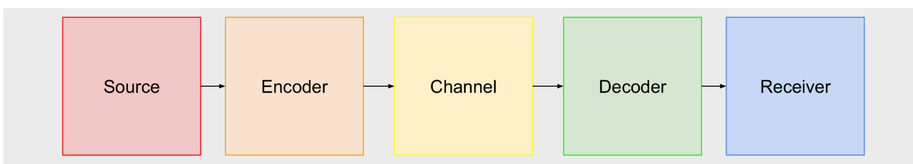
- *threshold* is the parking boundaries
- *sensorLeft* and *sensorRight* are the appropriate sensor data from each ultrasonic sensor
- *displayArrow* is a function producing the appropriately directed arrow

Our program will check if the sensor data exceeds the set threshold. If this is true, the car is parked *outside* of the bounds of the parking spot, and should be repositioned. This will turn on the alarm system (the buzzer and light system) which will only turn off under the condition that the driver repositions to the correct orientation in the parking spot.

3. **Shannon-Weaver Model of Communication**: Communicating with Driver

The Shannon–Weaver model of communication is a mathematical model, created in 1948, that describes the process of transmitting information from a sender to a receiver through a channel. It consists of five key components: the sender (source), the encoder (message preparation), the channel (medium of transmission), the decoder (message interpretation), and the receiver [30].

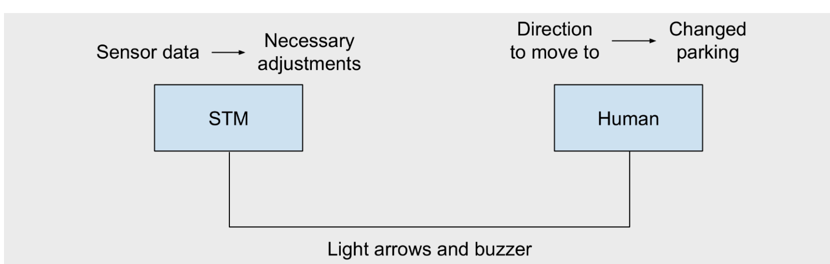
Figure 8: *The Shannon-Weaver model of communication.*



Where:

- The source is the ultrasonic sensor
- The encoder is the STM32
- The channel is the buzzer and the LEDs
- The decoder is the human
- The receiver is the parking position

Figure 9: *Implementation of the Shannon Weaver model in Park Pal.*



Within the context of Park Pal, the ultrasonic sensors act as the sender, detecting distance and sending information to the STM32, which acts as the encoder. The microcontroller processes this data as either violating or abiding by the parking boundaries and sends signals through the output channel, LEDs and buzzer. The LEDs and buzzer noise are interpreted by the human into the direction the car should be repositioned. The human driver then repositions the car to the correct orientation in the parking spot, indicating that the communicated information has been received.

Costs

Manufacturing and Implementation Costs

Bill of Materials

ITEM	Number of items	Cost (per item) [CAD]	Total cost [CAD]
STM32 Microcontroller Unit	2	$17.00	$34.00
HC-SR04 Ultrasonic Sensor	3	$6.00	$18.00
LED Matrix, Green	2	$0.80	$1.60
Piezoelectric Buzzer	2	$1.00	$2.00
TOTAL (including MCUs)	$55.60		

Component Manufacturers and Distributors

ITEM	Manufacturer	Location
STM32 Microcontrollers	STMicroelectronics	Mississauga, Ontario
HC-SR04 Ultrasonic Sensors	OSEPP Electronics	Richmond, British Columbia
LED Matrix, Green	SparkFun Electronics	Boulder, Colorado, USA
Piezoelectric Buzzer	Murata Electronics	Nagaokakyo, Kyoto, Japan

ITEM	Distributor	Location
STM32 Microcontrollers	DigiKey Canada	Thief River Falls, Minnesota, USA
HC-SR04 Ultrasonic Sensors	DigiKey Canada	Thief River Falls, Minnesota, USA
LED Matrix, Green	DigiKey Canada	Thief River Falls, Minnesota, USA
Piezoelectric Buzzer	DigiKey Canada	Thief River Falls, Minnesota, USA

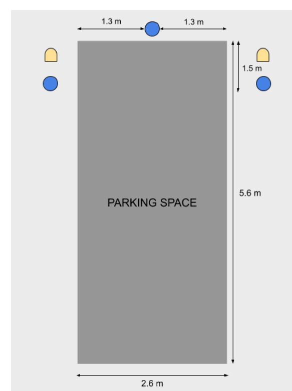
Installation Manual

First, find the desired parking space for installation.

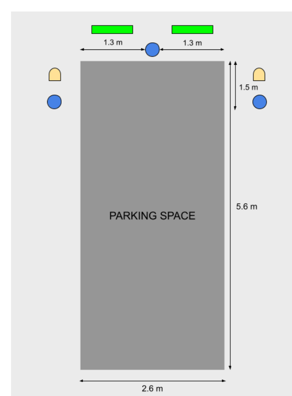
1. Place two side ultrasonic sensors 2.6 m apart, facing inwards to the rectangle.

2. Place each piezoelectric buzzer north of each ultrasonic sensor, such that the buzzer does not affect data measurements.

3. Place the third ultrasonic sensor 1.3 m horizontally and 1.5 m vertically from the side ultrasonic sensors.



4. Place the LED light stand in the center behind the topmost ultrasonic sensor, such that they are 1.3 m from the outer edge of the parking space.



User Guide

<u>How to operate</u>

To operate Park Pal, power it on and begin to park the vehicle into the allotted space. The ultrasonic sensors will measure the distance between the vehicle and the boundaries of the parking spot, triggering a buzzer and two LED matrices if the car is parked incorrectly. The LED matrices indicate the direction to reposition the parking in. Adjust parking until the indicators turn off, signaling that the vehicle is properly aligned within the space.

<u>Features and Functionalities</u>

- **Ultrasonic Distance Detection**
  - The system uses ultrasonic sensors to measure the distance between the vehicle and the parking spot boundaries. These sensors provide accurate, live feedback to ensure the vehicle is parked within the designated area.
- **LED Symbolic Feedback**
  - A series of LED lights indicate the vehicle’s alignment within the parking spot. If the car is parked incorrectly (ie. out of the parking bounds), specific LEDs will light up to signal the correct orientation to move in.
- **Buzzer Warning System**
  - When the vehicle is too close to the boundary or outside the parking spot,the buzzer emits an audible noise. This sound prompts the driver to correct the vehicle’s position before completing the parking.
- **Real-Time Monitoring**
  - The system continuously tracks the car’s distance from the boundaries, making instant updates through the ultrasonic sensors. This allows for real-time adjustments as the driver moves into the parking spot.

<u>Troubleshooting</u>

If the system is not responding:

- **Check power supply**: Ensure the system components are receiving a stable and sufficient power supply.
- **Verify wiring**: Check all connections for loose, incorrect, or faulty wiring between components.
- **Manual reset**: Shut down the system and repower to fix any possible calibration issues.

If the system is responding incorrectly:

- **Check environment**: Ensure no nearby objects or surfaces are interfering with the ultrasonic sensor's readings.
- **Manual reset**: Shut down the system and repower to fix any possible calibration issues.

If the system doesn’t stop responding:

- **Manual reset**: Shut down the system and repower to fix any possible calibration issues.
- **Ensure the sensor is not obstructed**: Check that the sensors are free from obstructions that may block their ability to detect properly.

Risks

Analyses

Power Analysis

STM32F401RE (2): [31]
V = 5 V
I = 0.1 A
P = I*V = 5*0.1 = 0.5 W
P*2 = 1.0 W

HC-SR04 Ultrasonic Sensor (3): [24]
V = 5 V
I = 0.015 A
P = I*V = 5*0.015 = 0.075 W
P*3 = 0.225 W

Green LED Matrix (2): [32]
V = 2.1 V
I = 0.02 A
P = I*V = 2.2*0.02 = 0.042 W
P*2 = 0.084 W

Buzzer (2): [22]
V= 3V
I = 0.03 A
P = I*V = 3*0.03 = 0.09 W
P*2 = 0.18 W

Total power:
Power = 1.0 + 0.225+0.084+0.18 = 1.489 W < 30 W
This does **not** exceed the maximum power limit of 30 W, and meets the project requirements

Energy Analysis

$E_{total} = E_p = mgh$
m = 2* 15g = 0.03 kg [33]
g = 9.81 m/s^2
h = 1.5 m
E_{total} = 0.001*9.81*1.5 = 0.44145 J < 0.5 J

This does **not** exceed the maximum energy storage limit of 500 mJ, and meets the project requirements.

Risk Analysis

From current testing of the prototype, there is little risk in using it, but some potential risks that are worth noting;

1. Safety impacts when used incorrectly: The system lies on the ground and could pose a hazard for cars as they could drive on top of the machinery destroying it and causing damage to their vehicle by puncturing the wheels. Even if drivers intend to park correctly, a sharp angle turn or incorrect alignment could damage the system and the vehicle.
2. Safety impacts when used correctly: The system could be considered a tripping hazard as it juts out of the ground in locations where most will not be looking downward.
3. Safety impacts when used in a manner not intended: The system could be used by vehicles of a non-standard size such as a semi-truck or motorcycle, which the system may not be able to recognize as the dimensions are different from the standardized vehicles.
4. A possible misuse of the system is using the sound of the buzzer to scare people or animals. Once someone approaches the empty lot, they may not be aware of the system in place and be alarmed to hear the buzzer reacting to their presence once the sensors detect it. Another possible misuse of the sensor is to cause a disturbance, as the buzzer will go off if something triggers the sensor, so placing something either by accident or on purpose could cause the buzzer to go off and cause a disturbance for others.
5. Possible malfunctions of the system:
    a. The sensor incorrectly measures the distance of the vehicle
    b. The buzzer plays at a different frequency than intended
    c. The buzzer plays at a volume that was not intended
    d. The buzzer does not emit a sound response
    e. The LED Matrix displays incorrect data on the vehicle's parking position
    f. The LED Matrix does not display any data on the vehicle's parking position
6. Possible consequences of these failure mechanisms:
    a. Inaccurate data is sent to the rest of the system resulting in providing the driver with inaccurate measurements and may cause the driver to park incorrectly
    b. The buzzer will create a disturbing sound (either too high or too low) which could even harm those who hear it, or it may be at a frequency inaudible to people
    c. The buzzer will create a sound that may be too soft to hear or too loud and cause a disturbance or even damage the hearing of those around it
    d. The buzzer will not give an audible response to the driver which could result in the driver being unaware of improper parking
    e. The LED Matrix will not give the driver correct information on where they are located and how they should move, so the driver may park incorrectly
    f. The LED Matrix provides no visual display and the driver is unable to assess their location and how they should move in order to fix their parking

Testing and Validation

Test Plan

Our test plan includes:

1. Test sensor accuracy (3. Parking spot distance)
    a. Setup: The HC-SR04 sensor has a detection range of 2-400 cm. To test its accuracy in detecting an object's distance, create a range of marked distances from the sensor on the floor. Then, position an object at these varying distances, and ensure the sensor reads the appropriate distance.
    b. Parameters: Distance (in centimetres)
    c. Test inputs: 2 cm, 30 cm, 50 cm, 100 cm, 200 cm, 400 cm
    d. Measurement standard: Distance from sensor (in centimetres)
    e. Pass/fail criteria: To pass, the sensor must read the correct distance in centimetres, with a permitted error of ± 0.3 cm
2. Test that the buzzer is audible from 1 meter away. (2. Sound)
    a. Setup: The buzzer should produce a constant frequency when an object is too close to it and exceeds the distance threshold specified in the code. A recording cellphone should be placed a measured 1 metre away from the buzzer, and a box should be placed in front of the ultrasonic sensor, exceeding the specified threshold. After the buzzer buzzes, stop recording.
    b. Parameters: Audible buzzer sound (1 meter away)
    c. Test inputs: Threshold distance (in centimetres)
    d. Measurement standard: The phone recorder detects any volume > 0.
    e. Pass/fail criteria: To pass, the phone must detect a volume > 0 from a distance of 1 meter away from the buzzer.
3. Test buzzer timing (8. Delayed guidance)
    a. Setup: The buzzer should begin buzzing five seconds after a parking error is detected. Place an object outside of the parking bounds, triggering the sensor to detect an error. Use a stopwatch to measure the time delay between the detection and when the buzzer starts.
    b. Parameters: Time (in seconds)
    c. Test inputs: Object placed outside of parking bounds
    d. Measurement standard: Stopwatch measurement of the time between error detection and buzzer activation.
    e. Pass/fail criteria: To pass, the buzzer must activate 5 seconds after detection, with a margin of error of ±0.5 seconds.
4. Testing that the lights blink in the right direction (4. Guidance system)
    a. Setup: Place objects outside the left and right boundaries of the parking space, simulating incorrect parking. Verify that the LED matrix blinks arrows in the direction the driver should move (i.e., left arrow when the car is too far right, and vice versa).
    b. Parameters: LED light direction
    c. Test inputs: Car too far left, Car too far right

d. Measurement standard: Visual inspection of the arrow direction on the LED matrix.
e. Pass/fail criteria: To pass, the correct direction must be displayed based on the parking error detected, with no directional mismatches. If the object is too far left, the light matrix should display a right arrow. If the object is too far right, the light matrix should display a left arrow. If the object is too far ahead, the matrix should display a down arrow.

5. Test that the buzzer emits the specified frequency. (6. Frequency)
    a. Setup: Set the buzzer outside the left and right boundaries of the parking space, within close proximity to the driver's final position. Verify that the frequency emitted by the buzzer is the correct frequency to be played when a parking error is detected with a cellphone application.
    b. Parameters: Frequency (in kHz)
    c. Test inputs: Object placed outside of parking boundaries
    d. Measurement standard: Frequency analyzer detects sound frequency in kHz.
    e. Pass/fail criteria: To pass, the buzzer must emit sound at 1 kHz with a permitted deviation of ± 0.5 kHz.

Bibliography

[1] City of Waterloo, City of Waterloo Census Bulletin, 2021. City of Waterloo. https://www.waterloo.ca/en/government/resources/Documents/Economic-Development/2021-Census-Bulletin-AODA.pdf (accessed Oct. 30, 2024)

[2] Statistics Canada, Circumstances surrounding pedestrian fatalities, 2018 to 2020. The Daily. https://www150.statcan.gc.ca/n1/daily-quotidien/231030/dq231030a-eng.htm (accessed Oct. 30, 2024)

[3] J. Ferrando, A. Plasència, I. Ricart, X. Canaleta, M. Seguí-Gómez, Motor-vehicle injury patterns in emergency-department patients in a south-European urban setting, Annu Proc Assoc Adv Automot Med. 2000;44:445-58. Available: https://pubmed.ncbi.nlm.nih.gov/11558100/. (accessed Oct. 30, 2024)

[4] C. Pilet, M. Galinski, S. Lafont, Chronic pain prevalence two years after a road crash and its biopsychosocial risk factors - Results from the ESPARR cohort, Journal of Transport & Health, May. 2023. Available: https://doi.org/10.1016/j.jth.2023.101613 (accessed Oct. 30, 2024)

[5] S. Pitel, R. Solomon, ESTIMATING THE NUMBER AND COST OF IMPAIRMENT-RELATED TRAFFIC CRASHES IN CANADA: 1999 TO 2010, MADD. https://www.madd.ca/media/docs/estimating_presence.pdf (accessed Oct. 30, 2024)

[6] A. Ramadan and M. Roorda, Impacts of Illegal On-Street Parking on Toronto's CBD Congestion, University of Toronto, https://uttri.utoronto.ca/files/2017/09/Impacts-of-Illegal-On-Street-Parking-on-Torontos-CBD-Congestion.pdf (accessed Oct. 30, 2024).

[7] L. Harrison, Toronto traffic is so bad, some are considering leaving the city, a new survey says, CBC News, https://www.cbc.ca/news/canada/toronto/congestion-survey-toronto-2024-1.7264164 (accessed Oct. 30, 2024).

[8] Y. Zhu, X. Ye, J. Chen, X. Yan, T. Wang, Impact of Cruising for Parking on Travel Time of Traffic Flow, Sustainability, Apr. 2020. Available: https://doi.org/10.3390/su12083079 (accessed Oct. 30, 2024)

[9] European Environment Agency, CO2 emissions from cars: facts and figures (infographics). European Parliament. https://www.europarl.europa.eu/topics/en/article/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics (accessed Oct. 30, 2024)

[10] L. O'Connor, Saskatoon City Hall contemplates how to collect more than $6m in unpaid parking tickets, CBC News, https://www.cbc.ca/news/canada/saskatoon/saskatoon-city-hall-to-collect-6-million-parking-ticket-fines-1.7286613 (accessed Oct. 30, 2024).

[11] CBC News, City of Ottawa forgives $2.6m in decades-old parking fines, CBC News, https://www.cbc.ca/news/canada/ottawa/ottawa-city-forgives-pre-amalgamation-parking-tickets-1.7224121 (accessed Oct. 30, 2024).

[12] B. Hristova, Hamilton drivers got over 143,000 parking tickets last year - here's where, CBC News, https://www.cbc.ca/news/canada/hamilton/hamilton-parking-tickets-2023-1.7195631 (accessed Oct. 30, 2024).

[13] M. Elliott, The number of parking tickets has plunged in cash-strapped Toronto. Why the lax enforcement?, Toronto Star, https://www.thestar.com/opinion/contributors/the-number-of-parking-tickets-has-plunged-in-cash-strapped-toronto-why-the-lax-enforcement/article_588cb2a7-843e-5e23-aef7-d8f2ff9afdb1.html (accessed Oct. 30, 2024).

[14] D. Cassens, W. Feist, Paint Failure Problems and Their Cure, Purdue University. https://www.extension.purdue.edu/extmedia/ncr/NCR-133.html (accessed Oct. 30, 2024)

[15] E. Paquette, P. Poulin, G. Drettakis, The Simulation of Paint Cracking and Peeling, Graphics Interface, 2002. Available: https://profs.etsmtl.ca/epaquette/Research/Papers/Paquette.2002/peeling.pdf (accessed Oct. 30, 2024)

[16] Transport Canada, Active parking assistance. Transport Canada. https://tc.canada.ca/en/road-transportation/driver-assistance-technologies/parking-assistance/active-parking-assistance (accessed Oct. 30, 2024)

[17] Increase visibility of stop signs: Leds around stop sign face, Center for Transportation Research and Education, https://ctre.iastate.edu/research-synthesis/intersections/stop-signs/leds/ (accessed Oct. 30, 2024).

[18] M. Yeh, J. Multer, and T. Raslear, An Application of Signal Detection Theory for Understanding Driver Behavior at Highway-Rail Grade Crossings, https://railroads.dot.gov/sites/fra.dot.gov/files/fra_net/1668/Application_of_SDT_for_Understanding_Driver_Behavior_at_GRX_(HFES09)_FINAL.pdf (accessed Oct. 30, 2024).

[19] Aaxel Insurance Brokers Ltd., The Truth About Parking Lot Accidents: Understanding Causes, Prevention, and Insurance Considerations, https://www.aaxel.ca/the-truth-about-parking-lot-accidents-understanding-causes-prevention-and-insurance-considerations/ (accessed Oct. 30, 2024).

[20] MTO, Traffic lights: Official Ministry of Transportation (MTO) driver's handbook, https://www.ontario.ca/document/official-mto-drivers-handbook/traffic-lights (accessed Oct. 30, 2024).

[21] R. Jimison, What it really means to see green, CNN, https://www.cnn.com/2017/06/05/health/colorscope-green-environment-calm/index.html (accessed Oct. 30, 2024).

[22] Piezoelectronic buzzers, Piezoelectronic Buzzers, https://www.mouser.com/datasheet/2/400/ef532_ps-13444.pdf (accessed Oct. 30, 2024).

[23] Audio frequency range: Seven crucial zones you need to know, SoundGym, https://www.soundgym.co/blog/item?id=seven-frequency-zones-you-must-identify (accessed Oct. 30, 2024).

[24] Sparkfun, Ultrasonic ranging module HC - SR04, https://cdn.sparkfun.com/datasheets/Sensors/Proximity/HCSR04.pdf (accessed Oct. 30, 2024).

[25] C. Robbins and S. Fotios, Road lighting and distraction whilst driving: Establishing the significant types of distraction, *Lighting Research & Technology*, vol. 53, no. 1, pp. 30–40, Apr. 2020. Available: https://doi.org/10.1177/1477153520916515 (accessed Oct. 30, 2024).

[26] LID Permeable Paving, Does Your Commercial Parking Lot Meet Ontario Requirements?. Parking Lot Requirements Ontario. https://lidpermeablepaving.ca/parking-lot-requirements-ontario/ (accessed Oct. 30, 2024)

[27] What is an ultrasonic/level sensor?, Keyence, https://www.keyence.ca/ss/products/sensor/sensorbasics/ultrasonic/info/ (accessed Oct. 30, 2024).

[28] LibreTexts, 17.3: Speed of sound, Physics LibreTexts, https://phys.libretexts.org/Bookshelves/University_Physics/University_Physics_(OpenStax)/Book%3A_University_Physics_I_-_Mechanics_Sound_Oscillations_and_Waves_(OpenStax)/17%3A_Sound/17.03%3A_Speed_of_Sound (accessed Oct. 30, 2024).

[29] W3Schools, C++ Conditions and If Statements, W3Schools, https://www.w3schools.com/cpp/cpp_conditions.asp (accessed Oct. 30, 2024).

[30] C. E. Shannon, A mathematical theory of communication, in The Bell System Technical Journal, vol. 27, no. 3, pp. 379-423, July 1948, Available: https://doi.org/10.1002/j.1538-7305.1948.tb01338.x.

[31] ECE 198 Instructors, STM32F401RE Guide. ECE 198 Learn Page. https://learn.uwaterloo.ca/d2l/le/content/1062117/viewContent/5641483/View (accessed Oct. 30, 2024)

[32] Dot Matrix LED 8×8 1088BS, Einstronic, https://einstronic.com/product/dot-matrix-led-8x8-1088bs/ (accessed Oct. 30, 2024).

[33] B. Jamison, LED Light and Power Source Specification. Evan Designs. https://evandesigns.com/blogs/evan-designs-news-and-how-tos/led-light-and-power-source-specification? (accessed Oct. 30, 2024)