Smart Parking System Design Document

1. Needs Assessment

1.1 Client/Customer Definition

The primary customers for our smart parking system are entities responsible for managing parking facilities that serve a diverse clientele, particularly focusing on accessibility and compliance with handicap parking regulations. Our solution is tailored to address specific demographic, geographic, and economic attributes of these customers.

- **1.1.1 Attributes of the Customer Base**
    - **Demographic**: Our customer base includes entities serving a wide age range, with particular emphasis on individuals with disabilities or limited mobility, who require convenient and accessible parking options. According to Statistics Canada, 27% of Canadians report having a disability [1], which highlights the need for accessible parking solutions across public and private facilities.
    - **Geographic**: Many of our target customers, such as shopping malls, hospitals, and transportation hubs, operate in densely populated urban centers where parking demand is high and available spaces are limited [2]. This geographic factor adds complexity to managing parking spaces effectively and underscores the value of real-time availability systems to reduce congestion.
    - **Economic**: Customers like healthcare facilities and commercial complexes are economically motivated to improve accessibility to avoid fines for non-compliance with handicap parking laws and reduce potential legal liabilities. Additionally, improved parking management can enhance customer satisfaction, which is critical for retaining business.

- **1.1.2 Challenges Faced by the Client**
    - **High Demand for Accessible Spaces**: With limited handicap spots available, especially in high-traffic areas like shopping malls and healthcare facilities, the demand often exceeds supply, leading to accessibility issues for disabled users.
    - **Misuse of Handicap Parking**: Unauthorized use of handicapped spaces by non-eligible drivers is a common problem, as noted by a study in *Rehabilitation Psychology* [3], which reports that illegal use of these spaces is perceived as a major issue by individuals with disabilities.
    - **Navigation Difficulties in Large Facilities**: In multi-level parking structures like those found in airports and malls, finding accessible spaces can be difficult without real-time guidance. The Universiti Sains Malaysia noted that 86% of drivers face difficulty locating parking spots in multilevel lots [4], often leading to frustration and congestion.

1.2 Competitive Landscape

➢ **1.2.1 Traditional Handicap Parking Signage Systems**

- **Description**: Traditional systems use designated signage to indicate accessible parking spots in public and private lots. These systems rely solely on physical markings and signage to reserve spots for individuals with disabilities.
- **How It Addresses the Challenge**: The signage makes handicapped spaces easily identifiable, aiming to reduce confusion and ensure reserved spaces for eligible drivers.
- **Shortcomings**: This approach lacks real-time information, often leading to misuse by non-eligible drivers. Additionally, without a means to track availability, drivers with disabilities may waste time and fuel searching for an available spot, especially during peak hours or in large, multi-level facilities. Studies show that static systems are frequently abused and contribute to the frustration of drivers who genuinely need these spaces [5].

➢ **1.2.2 Automated Parking Systems**

- **Description**: An automated (car) parking system (APS) is a mechanical system designed to minimize the area and volume required for parking cars. Like a multi-story garage, an APS provides parking for cars on multiple levels stacked vertically [6].
- **How It Addresses the Challenge**: Automated systems can efficiently transfer cars to open spots, reducing the time spent searching for parking and minimizing congestion. It maximizes the number of parking spaces while minimizing land usage.
- **Shortcomings**: Individuals with disabilities do not receive targeted assistance for finding accessible parking. Moreover, these systems can be costly and complex to install.

➢ **1.2.3 Mobile Parking Apps with Reservation Features**

- **Description**: Some mobile apps allow users to locate and reserve parking spaces in advance. Apps like ParkMobile and SpotHero offer users the ability to view real-time availability, make reservations, and even prepay for spots in certain facilities [7].
- **How It Addresses the Challenge**: By providing information on spot availability and allowing users to reserve spaces, these apps help users avoid long search times and reduce competition for spots. They also provide a degree of convenience for users who prefer digital solutions.
- **Shortcomings**: Although these apps are beneficial, they are generally not specialized for accessible parking needs, as they primarily cater to general parking. They also do not prevent unauthorized use of handicapped spaces by non-eligible users. Furthermore, these systems may require GPS tracking or app usage fees, potentially limiting their accessibility and affordability for all users.

1.3 Requirement Specification

- **1.3.1 Functional Requirements:**
    - User Input Response Time:
        - Requirement: The system must display available parking spots and accept license plate input within 1 to 2 seconds of user interaction [8] at the entrance.
        - Reasonable: Testable with a stopwatch to measure the system’s response time.
        - Justification: Ensures a smooth and efficient user experience. It also makes the whole process faster, helping resolve a part of our problem i.e., saving time, money and resources.

    - Parking Spot Selection and Confirmation:
        - Requirement: The system must update the database of available parking spots within 1 second after the user selects a spot [9].
        - Reasonable: Measurable using a stopwatch to measure the time taken from selection to database update.
        - Justification: Quick updates in the system prevent delays and conflicts in parking spot availability.

    - Inter-STM32 Communication:
        - Requirement: The STM32 at the exit gate must communicate the parking spot's vacancy status to the entrance gate within 100 milliseconds [11].
        - Reasonable: Testable by measuring the time between sending and receiving messages.
        - Justification: Ensures real-time updates and accurate parking spot availability.

- **1.3.2 Technical Requirements:**
    - Data Transmission Reliability:
        - Requirement: The STM32 communication system must maintain a 99% reliability rate over a distance of up to 50 meters [10].
        - Reasonable: Testable by measuring signal strength and data transmission at varying distances.
        - Justification: Ensures robust communication between the entrance and exit gates.

    - License Plate Storage Capacity:
        - Requirement: The system must be able to store and process at least 100 unique license plate entries simultaneously.
        - Reasonable for 1A Students: Measurable using a formula to calculate approximate entries.

- Measurable: RAM available in STM32: 96KB = 96 x 1000 = 96000 bytes [12]
  Bytes used while entering a license plate: 8 bytes(8 characters)
  Bytes for storing parking spot: 2 bytes
  Total bytes used for 1 entry: 8 + 2 = 10
  Total entries = (Number of bytes available)/(Bytes per entry)
  = 96000/10
  = 9600 entries
  Therefore, the system will be perfectly fine while storing 100 entries.
- Justification: Ensures the system can handle a reasonable number of entries.

➢ **1.3.3 Safety Requirements:**

- Power and Energy Restrictions:
  - Power Consumption:
    - Requirement: The design must not consume, transfer, discharge, or otherwise expend more than 30 watts of power [13] at any point in time.
    - Reasonable: Measurable with a multimeter or power meter.
    - Justification: Prevents overheating and ensures safe operation of all components.

  - Energy Storage Capacity:
    - Requirement: The system must not store or contain more than 500 millijoules (mJ) of energy [13] at any point in time.
    - Reasonable: Use an energy meter to check storage capacity.
    - Justification: Limits the risk of electrical discharge or mechanical hazards.

  - CSA Approval for Electrical Connections:
    - Requirement: Any component connecting to a 110V AC outlet must be CSA-approved [13].
    - Reasonable: Verify components for CSA approval.
    - Justification: Reduces risk of electrical hazards.

- Testing on Human or Animal Subjects:
  - Prohibition on Human or Animal Testing:
    - Requirement: Testing of the design on human or animal subjects is strictly prohibited [13].
    - Reasonable: Use non-invasive testing methods such as simulations.
    - Justification: Ensures adherence to ethical standards and safety.

2. Analysis

2.1 Design

➢ **2.1.1 System Overview:**

The smart parking system is designed to streamline and monitor the occupancy of parking spots in real-time, utilizing two STM32 microcontrollers, each paired with a dedicated laptop. One microcontroller-laptop combination is placed at the entry gate, while the other is located at the exit gate. Together, they form a cohesive system capable of managing parking spot occupancy with user interaction and updating statuses in a centralized database.

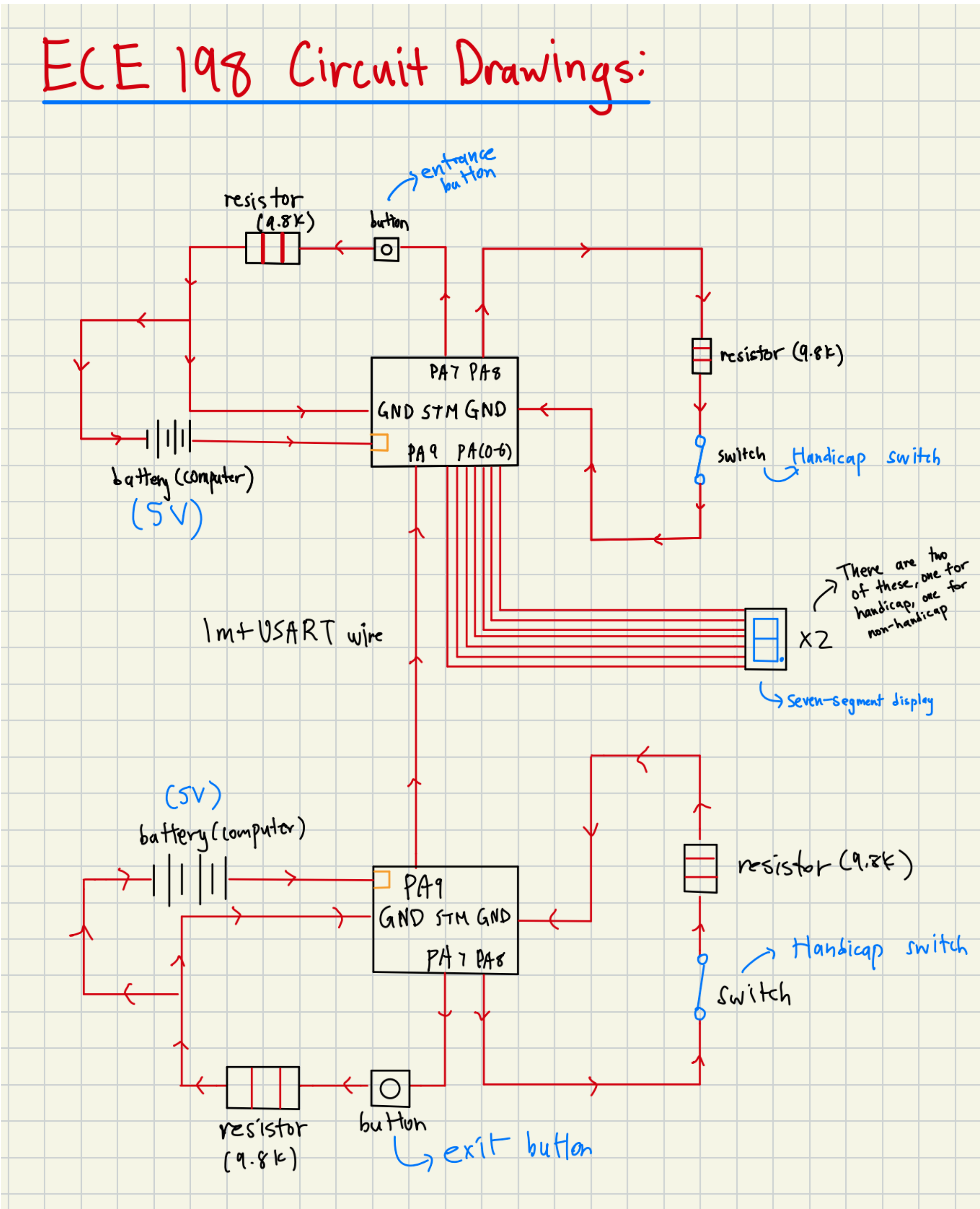
➢ **2.1.2 Purpose and Objective**

The main goal of this parking system is to monitor parking spots' availability efficiently and allow for real-time tracking. The system's features ensure that spots are marked as occupied or unoccupied based on vehicle entry and exit, including a specific feature to track disabled parking spots. By implementing a simple user interaction model via push buttons and switches, this system minimizes complexity while maintaining essential functionality for users and administrators.

➢ **2.1.3 System Components**

- **STM32 Microcontrollers**: One microcontroller is assigned to the entry gate and the other to the exit gate, enabling localized control and response at each access point.
- **Laptops**: Each STM32 microcontroller is connected to a dedicated laptop, which powers the microcontroller and facilitates data processing, database management.
- **Push Buttons**:
    - **Entry Button**: Located at the entry gate, this button is pressed when a car enters the parking lot.
    - **Exit Button**: Located at the exit gate, this button is pressed when a car exits the parking lot.
- **Disabled Parking Switches**:
    - Each gate has a switch that users can activate if they require a disabled parking spot. When toggled, this switch signals the system to indicate a disabled parking spot is occupied or vacated, allowing for efficient tracking of these specific spots.
- **Resistors**:
    - **6.8k and 9.1k Resistors**: These are integrated to manage current flow within the circuitry on the breadboards, protecting the STM32 microcontrollers from potential damage due to overcurrent and ensuring signal stability.
- **Jumper Wires**:
    - Male-to-Male, Male-to-Female, Female-to-Female Wires
- **Breadboards**: Two breadboards, one at each gate, serve as the foundation for mounting and organizing the circuit components, allowing for modular and stable connections.

- **Seven segment displays**: 2 displays, one for showing the number of spots left for general parking, and the other one for displaying the number of spots left for disabled parking.
- **Circuit Diagram:**



- **2.1.4 User Interface & Database Management**
    - The laptops serve as a dual-function interface for powering the STM32 boards and providing database connectivity.
    - The user interface displays the real-time status of parking spots (occupied/unoccupied) and highlights the availability of disabled parking spaces.
    - Through database updates triggered by button presses, the user interface immediately reflects changes, allowing for efficient management and oversight of parking space occupancy.

- **2.1.5 Advantages & Key Features**
    - **Real-Time Status Tracking**:
        - This system ensures parking availability is monitored and updated without delays, providing users with accurate information on spot availability.
    - **Simplified User Interaction**:
        - The entry and exit button interface allows drivers to mark their entry or exit effortlessly, without complex technology or sensor-based detection.
    - **Disabled Parking Accessibility**:
        - By incorporating dedicated switches for disabled parking spots, the system offers an inclusive solution for users with specific needs.
    - **Centralized Database and Interface**:
        - With two laptops managing the database and interface at each gate, real-time updates and power supply are efficiently centralized without additional external components.

- **2.1.6 System Limitations & Scope**
    - **Button-Based System**:
        - Unlike sensor-based systems that can automatically detect vehicles, this design relies on user interaction. This simplifies setup and maintenance but depends on users pressing the buttons consistently.
    - **Manual Database Updates for Disabled Parking**:
        - The disabled parking switches depend on users manually toggling the switch, making it less autonomous compared to fully sensor-integrated systems.

➢ **2.1.7 Operation & Use Case Scenarios**

1. System Initialization

Before users interact with the system, it must be initialized and ready to operate:

- **Database Setup**: The central database should be pre-configured with available parking spots, identifying spots that are accessible for general parking and those designated as disabled spots.
- **System Check**: Each laptop at the entry and exit gates is connected to its respective STM32 microcontroller and initialized to communicate with the central database. The user interface should display the current status of parking spots (occupied or unoccupied) and clearly indicate disabled parking availability.

2. User Interaction at Entry Gate

When a user enters the parking lot, they initiate the following actions at the entry gate:

- **Step 1: Parking Spot Selection**
  - The user approaches the entry gate, where a user interface (displayed on the entry gate laptop) shows the status of all parking spots, marking which spots are occupied, unoccupied, or designated as disabled spots.
  - The user selects an unoccupied parking spot by checking the interface and then prepares to proceed.
- **Step 2: Pressing the Entry Button**
  - The user presses the **Entry Button** located at the entry gate. This press is registered by the entry gate's STM32 microcontroller, which triggers a signal to the connected laptop.
  - The entry gate laptop communicates with the central database, marking the selected parking spot as **occupied**.
- **Step 3: Database and UI Update for Occupancy**
  - Upon pressing the entry button, the database updates the status of the selected parking spot, setting it to "occupied."
  - The laptop's user interface refreshes to reflect this status, displaying the parking spot as occupied. Other users can now see this change, indicating that the spot is no longer available.
- **Step 4 (Optional): Disabled Parking Spot Selection**
  - If the user needs a disabled parking spot, they toggle the **Disabled Parking Switch** located at the entry gate before pressing the entry button. This switch signals the system to update the database, specifically marking a disabled parking spot as occupied.
  - The user then presses the entry button, and the system registers the action, updating the database accordingly to reflect that a disabled spot is now occupied.

3. User Interaction at Exit Gate

When a user exits the parking lot, they perform the following actions at the exit gate:

- **Step 1: Pressing the Exit Button**
  - The user approaches the exit gate and presses the **Exit Button**. This press is registered by the exit gate's STM32 microcontroller, which then sends a signal to the connected laptop to update the central database.
  - The laptop updates the parking status, marking the specific parking spot as **unoccupied**.
- **Step 2: Database and UI Update for Availability**
  - Upon pressing the exit button, the central database is updated, setting the user's previous parking spot status to "unoccupied."
  - The exit gate laptop interface refreshes to reflect the availability of this parking spot. Other users approaching the entry gate will now see this spot as available in the interface.
- **Step 3 (Optional): Disabled Parking Spot Clearance**
  - If the user is vacating a disabled parking spot, they must toggle the **Disabled Parking Switch** at the exit gate before pressing the exit button. This toggle signals the system to update the status of the disabled parking spot specifically, indicating that it is now unoccupied.
  - After toggling the switch, the user presses the exit button, and the system registers this action, updating the database and the user interface to show that the disabled parking spot is available again.

4. Example Use Case Scenarios

- **Standard User Parking in a Regular Spot**
  - A driver enters the lot, checks the entry interface for available spots, and presses the **Entry Button** to mark their selected spot as occupied.
  - After parking, they leave, and upon exit, they press the **Exit Button**, which updates the system to mark the spot as unoccupied.
- **User Parking in a Disabled Spot**
  - A driver requiring a disabled parking spot approaches the entry gate and toggles the **Disabled Parking Switch** before pressing the **Entry Button**. The system marks a disabled spot as occupied.
  - Upon leaving, the driver toggles the **Disabled Parking Switch** at the exit gate and presses the **Exit Button** to update the system, marking the disabled spot as unoccupied.

5. Error Handling and Troubleshooting

- **Button Misuse or Pressing Errors**
  - In cases where users mistakenly press a button without occupying or vacating a spot, the system includes a refresh feature on the laptops. This allows administrators to manually correct occupancy status through the interface.

- **Switch Misuse**
    - If a user mistakenly toggles the disabled parking switch without requiring a disabled spot, the administrator can reset this setting in the database. Additionally, instructions on proper use of the switch can be displayed on the user interface to prevent misuse.

➢ **2.1.8 Requirements**

2.1.8.1 Functional Requirements

1. **User Input Response Time**
    - Requirement: The system should display available parking spots and accept license plate input within 1–2 seconds of user interaction at the entrance.
    - Implementation:
        - The STM32 microcontroller, coupled with the entry gate laptop, facilitates efficient processing and immediate data handling. When the user inputs their license plate and selects a parking spot, the laptop quickly verifies and displays the availability status, leveraging fast, wired communication with the STM32 to minimize response time.
        - The minimal input-processing load and direct connection of each STM32 to a dedicated laptop ensure rapid response, meeting the target time.
    - Justification: This setup provides the necessary speed for a smooth user experience, reducing time and resource consumption by minimizing wait times.

2. **Parking Spot Selection and Confirmation**
    - Requirement: The system must update the database of available parking spots within 1 second after the user selects a spot.
    - Implementation:
        - Upon selecting a parking spot, the entry gate STM32 immediately transmits this information to the central database, marking the spot as occupied in real time.
        - Direct communication between the entry gate's STM32 and the laptop ensures that updates are sent and logged efficiently, keeping the database current and preventing conflicts in spot availability.
    - Justification: This rapid update functionality ensures spot availability accuracy, preventing issues like double-booking and facilitating efficient parking management.

3. **Inter-STM32 Communication**
   - Requirement: The exit gate STM32 must communicate the parking spot's vacancy status to the entry gate within 100 milliseconds.
   - Implementation:
     - A direct, wired connection between the two STM32 microcontrollers allows for real-time data transmission. When a spot is vacated, the exit gate STM32 sends a vacancy status signal to the entry gate's STM32, which updates the status in the database and on the user interface within milliseconds.
   - Justification: The direct connection between STM32s provides the low-latency communication required to maintain real-time updates on parking availability, improving the system's reliability.

2.1.8.2 Technical Requirements

1. **Data Transmission Reliability**
   - Requirement: The STM32 communication system must maintain a 99% reliability rate over a distance of up to 50 meters.
   - Implementation:
     - The system's wired setup between entry and exit STM32 microcontrollers minimizes interference, thereby achieving a high data transmission reliability rate.
     - For testing, signal strength and transmission consistency can be checked across varying distances and scenarios, confirming that the design meets the 99% reliability target.
   - Justification: Wired communication inherently minimizes signal degradation, ensuring robust data transfer essential for consistent operation.

2. **License Plate Storage Capacity**
   - Requirement: The system must store and process at least 100 unique license plate entries.
   - Implementation:
     - With 96 KB of RAM, the STM32 microcontroller can efficiently store up to 9,600 entries, far exceeding the required 100 unique entries. Each entry, consuming approximately 10 bytes (8 for the license plate and 2 for spot allocation), leaves ample memory available.
     - Testing with simulated license plates further confirms that the STM32 can handle this capacity without slowing down or losing data.
   - Justification: This ample storage ensures the system can handle not only the current load but also any future increase in user entries, ensuring scalability and durability.

2.1.8.3 Safety Requirements

1. **Power Consumption:**
    - Requirement: The design must not consume more than 30 watts of power.
    - Implementation:
        - The STM32 microcontroller and laptops draw minimal power due to their low energy requirements, and power to each STM32 is provided through USB connections to laptops, keeping power usage well below 30 watts.
        - Testing with a multimeter will verify the power consumption across the circuit, ensuring compliance.
    - Justification: This restriction reduces the risk of overheating and ensures the components operate safely within their limits, contributing to both user safety and component longevity.

2. **Energy Storage Capacity:**
    - Requirement: The system must not store or contain more than 500 mJ of energy.
    - Implementation:
        - The STM32 and associated circuitry have minimal energy storage capacity, as power is directly supplied from laptops with limited internal energy storage and no additional high-energy storage components.
        - Testing energy levels with an energy meter confirms compliance with the 500 mJ restriction.
    - Justification: By keeping energy storage low, the system minimizes the risk of electrical discharge or other potential hazards, maintaining a safe operating environment.

3. **CSA Approval for Electrical Connections:**
    - Requirement: All components connecting to a 110V AC outlet must be CSA-approved.
    - Implementation:
        - The laptops connected to AC outlets are commercially manufactured and CSA-approved, while all other components operate on DC, avoiding direct AC connection.
    - Justification: Using CSA-approved equipment ensures safety against electrical hazards, as mandated for components that directly connect to AC power.

4. **Testing on Human or Animal Subjects**
    - Requirement: Testing of the design on human or animal subjects is prohibited.
    - Implementation:
        - No direct interaction with human or animal subjects is required for this project. Testing can be performed through simulations and equipment, such as using dummy inputs and software simulations, avoiding any ethical concerns or risks associated with live testing.
    - Justification: The prohibition aligns with ethical standards and avoids unnecessary risk, maintaining focus on non-invasive testing.

➢ 2.1.9 Alternative Solutions

In designing a parking lot management system with two STM32 microcontrollers, several options for detecting vehicle presence were considered. The primary alternatives were:

- **Ultrasonic or Infrared Sensors [14]**:
    - Sensors could be installed at each parking spot to detect the presence of a vehicle, allowing the system to automatically register whether a spot is occupied. This option requires calibration for accurate detection and careful consideration of sensor placement and interference (such as ambient lighting for infrared sensors).
- **Inductive Loop Sensors [15]**:
    - Inductive loop sensors, often used in large parking facilities, could detect vehicles entering or exiting specific areas. While effective for high-traffic facilities, this solution would require more complex installation and additional signal processing to integrate with STM32 microcontrollers.
- **Push Buttons or Switches** (selected):
    - Using a simple push-button or switch system at the entrance allows the user to manually indicate when a vehicle has entered the parking lot or to confirm when a spot is open. This solution minimizes the need for sensors at each parking spot and relies on user input at the entrance instead of a fully automated system.

Quantitative Justification:

The choice of push buttons and switches over sensors for this parking lot project is based on the following considerations:

- **Cost-Effectiveness**:
    - Push buttons are generally more affordable than sensors, especially when scaling for multiple parking spots.
- **Simplicity in Wiring and Setup**:
    - Implementing push buttons significantly reduces the complexity of wiring as compared to installing multiple sensors. This setup also minimizes potential

points of failure, as sensors may require careful calibration and maintenance to function correctly over time.
- **Reliability for Low-Volume Parking**:
    - For a smaller parking facility where user input can be trusted for low-volume traffic, push buttons offer a robust solution without requiring automated sensor calibration.
- **Reduced Debugging and Maintenance Requirements**:
    - Push-button systems are less likely to need maintenance and do not require recalibration, which aligns with the project's objective of creating a simple, reliable system.

➢ 2.1.10 Application of Principles

1. **Boolean Logic (Binary Inputs and Outputs)**
    - **Principle [18]**: Boolean logic forms the foundation of digital computing, using binary (0 and 1) states to make decisions based on specific conditions.
    - **Application in Project**: In your parking system, Boolean logic enables the STM32 microcontrollers to assess whether a parking spot is occupied (1) or available (0). For example, a "1" is registered when a button is pressed, signaling a spot as taken, and a "0" when the spot is available. Boolean logic gates like AND, OR, and NOT allow the microcontrollers to process multiple inputs (e.g., all available spots) to guide users to the next open spot.
2. **Power Management(Current and Voltage Regulation)**
    - **Principle [19]:** Electrical devices require stable power to function reliably. Voltage regulation maintains a consistent voltage level, while current regulation controls the amount of current flowing through a circuit to prevent damage from fluctuations.
    - **Application in Project:** In our parking lot system, the STM32 microcontrollers, sensors, and other components will be provided a steady amount of power and voltage. This regulation would be calculated using Ohm's law: $V = IR$. Using this formula will allow us to properly determine electrical requirements.
3. **Kirchhoff's Voltage Law in Circuits**
    - **Principle**: Kirchhoff's Voltage Law (KVL) states that the sum of all voltages around a closed circuit loop must equal zero. This means that the total energy supplied by sources (like batteries) is equal to the total energy used by the components (like resistors, sensors, and displays) within that loop.
    - **Application in Project**: In the smart parking system, Kirchhoff's Voltage Law will be applied to ensure that the voltage supplied by the power source is appropriately distributed among the STM32 microcontrollers, sensors, and the seven-segment display. By using KVL, the voltage drops across each component can be calculated, ensuring that each part of the circuit receives the right voltage to operate effectively. This will help in preventing components from underperforming or being damaged due to voltage imbalances, ultimately ensuring the reliable operation of the parking system.

3. Costs

3.1 Bill of Materials and Manufacturers

Quantity	Material	Cost	Manufacturer	Location
40	Male-to-male jumper wires	$0.20	EDGELEC	China
40	Male-to-female jumper wires	$0.20	EDGELEC	China
40	Female-to-female jumper wires	$0.15	EDGELEC	China
2	Large breadboards	$14.60	REXQualis	Shenzhen, China
2	Dip Switch	$2.80	Taiss	Suzhou, China
2	Push Buttons	$1.20	DAOKI	China
3	6.8k Ω Resistors	$0.30	EDGELEC	China
3	9.1k Ω Resistors	$0.30	EDGELEC	China
2	Seven Segment Display	$2.80	Oiyagai	China
		Total Cost: $22.55		

3.2 Installation Manual

1. Take two laptops and connect the two STM32 nucleo boards to the laptops using the provided USB cables.
2. Entry gate:
    a. Using the jumper wires, wire and configure the STM32 board with the breadboard and then connect the resistors, push buttons, switches and the seven-segment displays on the breadboard. Use the diagram provided in the analysis section to build the circuit.
3. Exit gate: Follow the same process as the entry gate. However, the exit gate does not have the seven-segment displays mounted on the breadboard. To build the circuit, follow the diagram provided below.
4. Connect the two STM32 boards with each other using the diagram provided in the analysis section.
5. Import the code for the system into the STM32 Nucleo board using STMCubeIDE.

3.3 User Guide

1. **Scenario 1: General Parking**
    a. The user arrives at the entrance of the parking spot and wants to use the general parking spot.
    b. They check the number of remaining general spots on the seven-segment display. If there are no spots left they leave.
    c. If there are spots, they will turn the switch OFF if it is not already.
    d. Then they click the push button and enter the parking lot.
    e. When exiting the parking lot they will again ensure that the switch is off and then press the push button provided there to leave.

2. **Scenario 2: Disabled Parking**
    a. The user arrives at the parking lot and wants to park in one of the disabled parking spots.
    b. They check if there are any available.
    c. If there are available spots, they will turn the switch ON if not already.
    d. Then they click the push button and enter the parking lot.
    e. While exiting, they will turn the switch on and then press the push button to leave the parking lot.

4. Risks

4.1 Energy Analysis

➢ **4.1.1 Energy Analysis**

- For our project, using a relevant reference standard for baseline power levels would be the **IEEE 802.3** [16]. This standard provides guidelines for efficient power use in wired communication systems, making it suitable for applications like a small parking lot that relies on minimal energy consumption. The baseline power level according to IEEE 802.3 aligns with typical requirements for low-power wired devices, which helps maintain reliable performance while reducing power usage. With the STM32 microcontroller consuming around 0.5 W of power, this falls within the low-power range outlined by the standard. Following IEEE 802.3 ensures that the system's power usage meets industry expectations for small, energy-efficient, wired systems.

- The voltage provided by the USB port in the computer is 5V. The STM's internal voltage can be up to 5V and current can be 0.1 A according to the STM document [17]. Therefore, using the following equations we came up with power of 0.5W:

$$P = IV$$

$$P = (0.1A)(5V)$$

$$P = 0.5W$$

- Our project does not require significant energy storage and will obtain its power from the grid. Since we do not have a battery or capacitors within our circuits, and neither do any of the components in our circuit, we are not storing any chemical potential energy. We also do not have components such as springs storing mechanical energy. Meaning, there is a very minimal amount of energy stored within the system during operation. There is only some electrical energy powering the system while it is running.

4.2 Risk Analysis

➢ **4.2.1 Risk Analysis**

- Our product is intended to positively impact the lives of disabled drivers by making it simpler for them to navigate multi-level parking spots. However, as any other product/system, there are negative consequences as a result of using the system as intended. Firstly, manufacturing, installing and construction of the system all create carbon emissions. When the cradle-grave life cycle of the product is considered, there will be considerable emissions for the manufacturing and disposal of the system. During the use, the system will require electricity to operate. This additional electricity will also generate carbon emission. Other than environmental impacts, there will be no major negative consequences through the intended use of our product.
- If the system is used incorrectly, it could lead to several negative consequences for both safety and the environment. Incorrect usage, such as improper sensor calibration, could cause inaccurate parking availability indications, leading to confusion among drivers and potential traffic congestion as they search for parking spots that may not be available. This could result in safety risks due to sudden driving maneuvers and an increase in emissions due to prolonged idling. Additionally, frequent errors may overburden the system's components, leading to accelerated wear and the need for replacements, which could increase environmental waste.
- Misuse of the system, such as tampering with sensors or applying it in unsuitable environments, could lead to several safety and environmental concerns. For instance, if sensors are obstructed or manipulated, they may fail to provide accurate data, resulting in unsafe situations where drivers rely on incorrect parking information. Misuse could also cause the system to draw excessive power or send unnecessary signals, leading to increased energy consumption and a higher carbon footprint. Over time, misusing the design in unintended ways may degrade system

reliability, necessitating more frequent repairs or replacements and contributing to environmental waste.

- Potential malfunctions could arise from sensor failures, communication errors between microcontrollers, or software bugs in the system's processing algorithms. Sensors could fail due to physical wear or exposure to harsh environmental conditions, while communication issues might stem from electromagnetic interference or damaged wiring. Additionally, software bugs could disrupt data processing, causing the system to relay incorrect parking information. Power outages or component overheating may also affect system performance, potentially leading to intermittent or complete failure.
- Each of these failure mechanisms has its own set of safety and environmental consequences. Sensor failures may lead to inaccurate parking data, posing safety risks for drivers attempting to navigate the parking lot based on unreliable information. Communication errors between microcontrollers could lead to delays in data transmission, which may confuse drivers and lead to congestion. Software bugs may cause the system to frequently relay incorrect information, resulting in unnecessary idling and emissions. Power outages could render the system unusable, forcing drivers to search manually for parking and potentially increasing traffic congestion and fuel consumption. Lastly, component overheating may necessitate frequent replacements, contributing to environmental waste and additional emissions from the manufacturing and disposal of replacement parts.

5. Testing & Validation

5.1 Test Plan

➢ **5.1.1 Test 1: Entry Board Queue Management & Signal Response**

- **Test Setup:** The STM32 board is set up at the entrance and its queue management routine is deployed, simulating drivers entering the parking lot. A button or triggered board is used to simulate a driver joining the queue.
- **Environmental Parameters:** Standard indoor setup with a stable power supply (e.g., battery supply).
- **Test Inputs:** Trigger the button to simulate three consecutive drivers joining the queue.
- **Measurement Standard:** Check the queue order stored in the entrance board and verify the correct signaling for each driver joining.
- **Pass/Fail Criteria:** The test passes if the entrance board processes each entry in the correct order, confirming a response within 1 second of each trigger.

➢ **5.1.2 Test 2: Real-Time Spot Availability Signal from Exit to Entry Board**

- **Test Setup:** Connect the exit and entrance STM32 boards with a UART cable over a 1.5-meter distance. Simulate a car leaving the parking lot by pressing a button on the exit board, which should send a signal to the entrance board.
- **Environmental Parameters:** Controlled indoor environment.
- **Test Inputs:** Trigger the exit board to simulate the departure of a car from a parking spot.

- **Measurement Standard:** Measure the response time of the entrance board to receive the signal and update the spot availability (should be instant).
- **Pass/Fail Criteria:** The test passes if the entrance board accurately receives the signal and updates the spot status within 1 second of the departure signal.

➢ **5.1.3 Test 3: Disabled Spot Authorization at Entry Board**

- **Test Setup:** Configure the entrance STM32 board with a "disabled parking authorization" toggle. Simulate a driver attempting to access a disabled spot by pressing a button or switch.
- **Environmental Parameters:** Standard indoor setup with stabled power and UART connection.
- **Test Inputs:** Trigger the toggle on the entrance board to simulate both authorized and unauthorized driver attempts for disabled parking access.
- **Measurement Standard:** Verify the board's response to allow or deny access based on the simulated authorization status.
- **Pass/Fail Criteria:** The test passes if the entrance board constantly denies access to unauthorized drivers and allows access for authorized ones (use while loop in software).

➢ **5.1.4 Test 4: Data Synchronization & Status Update Between Boards**

- **Test Setup:** Deploy and initialize the entrance and exit STM32 boards. Simulate entry and exit scenarios multiple times to test data synchronization.
- **Environmental Parameters:** Indoor setting with minimal interference.
- **Test Inputs:** Send alternating entry and exit signals and verify the synchronization of parking spot availability on each board.
- **Measurement Standard:** Inspect the spot availability status stored on each board after every signal to check for consistency.
- **Pass/Fail Criteria:** The test passes if both boards maintain an accurate and synchronized parking spot status throughout all simulated scenarios.

➢ **5.1.5 Test 5: Load & Response Time Under High Traffic Conditions**

- **Test Setup:** Set up a simulation where multiple entry and exit signals are triggered in rapid succession on both boards to simulate high traffic conditions.
- **Environmental Parameters:** Controlled environment with reliable power and UART connectivity.
- **Test Inputs:** Trigger rapid entry and exit signals (e.g., 5+ times quickly) on each board to simulate high traffic.
- **Measurement Standard:** Measure each board's response time and ability to keep up with rapid updates without error.
- **Pass/Fail Criteria:** The test passes if each board accurately updates and processes each signal within 1 second without error or missed signals.

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