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Original Article

A Scalable Smart Parking Management System with a Client Mobile Application

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Abstract - *As urban migration continues to increase, many modern vehicle users tend to rely on established navigation system technologies to locate their destinations easily. However, particularly in large public parking lots, securing convenient parking slots close enough to the driver's destination of interest is a common challenge. Similarly, many non-expert drivers have issues parking without assistance. The proposed smart system thus tackles these challenges by proffering a parking slot assignment and route navigation system, which uses a novel algorithm to assign vehicles to the closet vacant parking slot to their desired destination and Dijkstra's algorithm to identify the best route within the parking lot. Using appropriately placed ultrasonic sensors and color-coded light indicators, unmanned parking assistance was provided. A mobile application was built to serve as the user interface for the drivers to book and receive parking slot assignments. The parking slot assignment validity was tested with a scenario of a shopping complex parking on a busy day, and the smart parking system gave optimal parking slot allocation to users via the mobile application. Subsequently, it was estimated that operating the smart parking system could save 1.609Kg of CO emission in a year.*

Keywords - *Android application, Navigation system, Sensor placement, Smart parking.*

1. Introduction

Automobiles have been projected by experts to increase to 2 billion by 2040 [1]. Proper infrastructure must be available to accommodate the rise in automobiles and the human population within a limited landmass. Metropolitan areas and busy environments like shopping malls, entertainment centers, and airports experience immense traffic issues, sometimes due to improper parking of vehicles or the unavailability of adequate parking systems. Drivers who face difficulties in parking their vehicles in these areas end up wasting time, fuel, and money, which in turn leads to traffic congestion and environmental pollution [2].

An effective system must be made available to cater for the proper distribution of vehicles in congested areas, hence the need for vehicle parking systems. Car parking systems are developed with a mindset to manage the parking of vehicles effectively. Some solutions have been developed to provide parking information to vehicle drivers with and without the presence of human interventions.

In a bid to improve the functionality of existing parking systems, new technologies have been incorporated into existing ones, such as smart parking systems based on agent models, based on Fuzzy logic technology, Wireless Sensor Networks, Vehicular infrastructure communication (V2I), Global Positioning Systems GPS, Computer vision, RFID technology, other hybrid systems [3].

This paper presents the development of a parking system that will operate by sensing the availability of parking spaces using ultrasonic sensors. Car owners can request free parking spaces from a parking management system using a mobile application connected to a cloud-based server. The system utilizes WebSocket connectivity for real-time communication between the IoT device and the cloud server. Slot allocation and shortest route algorithms were also implemented to provide the shortest possible distance for drivers to take in securing a parking slot, taking the distance to the desired destination as a factor. The system also provides parking assistance for the drivers for better navigation, parking, and unparking. The rest of the paper is organized as follows. Section 2 presents the related work in this study area, while section 3 discusses the system design and implementation. The results obtained are presented in section 4, and section 5 concludes the paper.

2. Related Work

Many studies have been carried out on smart parking systems using different technologies, some of which are presented here. [5] Ultrasonic sensors were proposed for detecting occupancy status in a multilevel parking lot and improper parking detection. LEDs are also used for displaying the number of vacant spaces, navigation of the vehicles, and the states of the parking lot.

Also, [6] proposed using a microcontroller and ultrasonic sensor network to detect the occupancy of vehicles in a parking lot. The drivers are provided with a mobile application to find an available slot or to reserve a slot with payment options. In the case of an absence of a mobile application, the driver can request a lot by looking at a monitor at the entrance. A downside to this system is the requirement of a human staff to process, verify and allocate the slot, which is prone to error instead of an autonomous process. In addition, the driver is also required to check if the lot is empty, as this could lead to additional time wastage.

In providing a new approach to the smart-parking concept, [7] proposed a solution that considers the dimensions of the vehicles taking into account the size of the vehicles instead of their number within a parking lot, optimizing thus the number of parking spaces. It aimed at increasing the capacity of the parking slots by more than 30% using low-cost hardware.

Applying Wireless Sensor Networks, [8] developed a parking system which operated by sensing parking spaces using a magnetometer as the sensing device. The Wireless Sensor Network was used to ensure the forwarding and routing of data to the base station wirelessly, which was used to measure the conditions of interest, such as magnetic (metal) fluctuations and light radiation (radiation or reflection of light from objects).

In the same vein, [9] detects the presence or absence of a vehicle by measuring the amount of ambient light using a light sensor. Using an adaptive threshold algorithm, it compared the light intensity with a suitable threshold. It uses ZigBee as the communication protocol. This method is unreliable for outdoor parking as it requires additional sensors to make this possible.

[10] proposed the use of two different sensor networks - an ultrasonic sensor for indoor parking lots and a magnetic sensor for outdoor parking lots and also leveraging the Bluetooth communication between the phone and the sensor network.

In [11], an IoT-based parking system with online booking functionality was proposed. It uses RFID tags and readers to authenticate the vehicles for first-time and existing users. A web interface is also provided for visualizing the system's performance.

Furthermore, [12] presented a work on Smart Parking System Based on the Visual-Aided Smart Vehicle Presence Sensor (SEI-UVM), which consists of three components of an IoT sensor-based device, a mobile application, and a monitoring station. It also provides a detailed illustration of providing slot status incorporating driver assistance functionality. It uses cameras to identify the number plates of the vehicles.

3. Proposed Approach

This section presents the description of the system operation and functional design, the sensing technology, states, and various features that make this work unique.

3.1. General System Description

The system can allocate free parking spaces to drivers on request through their smartphones. The process involves an initial registration of a user account by the driver via the mobile application. Subsequently, to book an optimally available parking space, the driver searches for a free parking spot closest to his desired destination by simply inputting his/her destination and entry gate into the mobile application. The request is sent to a back-end web service that searches for a free parking spot based on received sensor information and sends the required instruction message to the driver, stating the parking space as well as the recommended route. This chapter will take a detailed look at the steps and procedures involved in actualizing the system design and implementation. The system design is divided into two (2) aspects, namely:

1. Hardware circuit design and sensing technique considerations
2. Software design and development
    a) Web Application – Application Programmable Interface (API)
    b) Mobile Application

The hardware section consists of a microcontroller-based circuit that interfaces with the sensors and indicators and sends the sensor status to a web server via a wireless channel. On receiving the data, the webserver saves the sensor status into the database and allocates a free parking spot to the driver on request using an efficient allocation algorithm. The mobile application provides a graphical user interface for the driver to request a slot and receive routing information to a suitable available slot.

Figure 1 gives an overview of the system showing the interaction between different functional components.

3.1.1. Sensing Technique

The ultrasonic sensor is described as a non-intrusive sensor because it does not require contact to detect vacant spaces used in a smart parking system. An ultrasonic sensor transmits air pressure waves via sound energy at frequencies between 25 and 50 KHz, above the human audible range. These also measure the vehicle's distance from the sensor by detecting the portion of the transmitted energy reflected towards the sensor from an area defined by the transmitter's beamwidth. [13].

The sensors shoot a beam of sound that travels until it hits an object. The sound wave then bounces back and returns to the sensor. The sensor then measures the time it takes the sound wave to travel and calculates the distance between the sensor and the object. The received ultrasonic energy is converted into electrical energy analyzed by signal-processing electronics that are either collocated with the transducer or placed in a roadside controller. Ultrasonic sensors may be used in conjunction with other sensor technologies to enhance presence and queue detection, vehicle counting, and height and distance discrimination. Ultrasonic sensors can be used for counting vehicles and assessing the occupancy status of each parking space [5]. Despite the low cost and easy installation of ultrasonic sensors, they do have some disadvantages, particularly sensitivity to temperature changes and extreme air turbulence.

The ultrasonic sensor works on three operating modes: reflection mode, direct measurement mode, and pulsed versus continuous measurement mode. For this application, the setup is in the reflection mode, in which an ultrasonic transmitter emits a short burst of sound in a particular direction. The pulse bounces off a target and returns to the receiver after a time interval. The receiver records the length of this time interval and calculates the distance traveled based on the speed of sound. The distance, d_i The target from the sensor is calculated by making the formula in Equation 1.

$$d_i = \frac{1}{2} * \omega_n * t \qquad (1)$$

Where t is the time between the sending of the triggering wave and the receiving of the echo signal and ω_n Is the speed of the ultrasonic wave in the traversing medium.

3.1.2. Sensor Placement

To achieve high fidelity from the data required from the ultrasonic sensors, the position of the sensor has to be validated. Otherwise, there might be many false records on parking slots' occupancy. A methodology to justify the vertical and horizontal positioning of the sensor to make an optimal impact is thereby proffered.

The ultrasonic sensors are placed in each parking slot. Thus, the maximum distance to begin vehicle detection should be analyzed for a realistic measurement. The placement of the sensors above the ground and sensor-to-sensor interspacing to avoid interference also need to be justified.

Ultrasonic sensors typically send out divergent trigger signals at an angle, θ_m. For a standard parking slot of length, l_b and width, w_b, the horizontal placement of the sensor has to be such that the signal from a given slot does not read a false positive indication from the presence of a vehicle parked in an adjacent parking slot. The center of the parking slot would be a good position worth testing to verify the viability of the use of an ultrasonic sensor for this operation, as shown in Figure 3. Thus, for a sensor with a distance measurement range of maximum value, l_m The trigonometric relations can be used to evaluate the sensor's radial signal coverage.

$$\sin\frac{\theta_m}{2} = \frac{opp.}{hyp.} = \frac{w_m/2}{l_m} \qquad (2)$$

$$w_m = 2l_m \sin\frac{\theta_m}{2} \qquad (3)$$

where, w_m Is the width of the sector, chord.

If $w_b > w_m$, then the sensor is suitable to the placed at the central position in front of each slot without fear of having readings based on vehicles within adjacent slots. Otherwise, a device with a shorter range or less divergence angle must be sought.

Similarly, a sensor distance range suitability criterion is $l_b > l_m$.

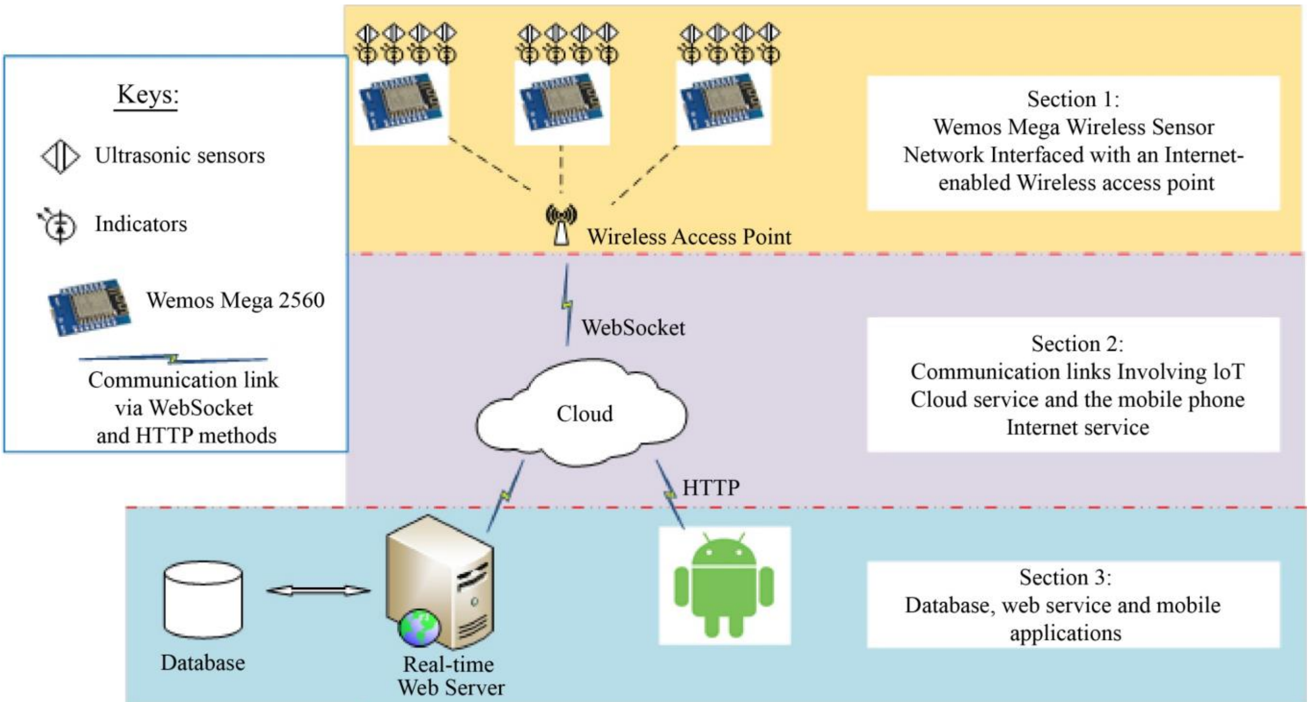


Fig. 1 Overview of parking management architecture

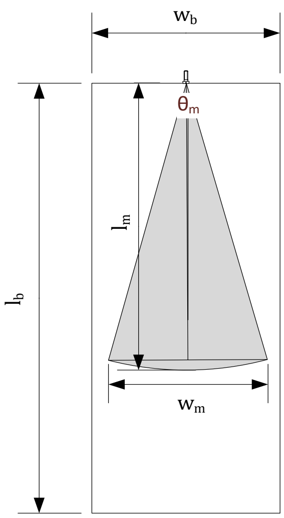


Fig. 2 Justification for horizontal placement of sensors in the parking slot

The width of the divergence of the trigger beam at the maximum measurable distance is equally considered to determine the placement height and hm of the sensor from the ground level. The sensor should be placed at a height of at least. $w_m/2$ above the ground to avoid false positive readings due to reflections from the ground. For vehicle detection with parking assistance, however, the sensor needs to be positioned as much as possible such that the front of the bonnet (nameplate area) is part of the car that is first reflected by the ultrasonic beam. The ultrasonic sensor modules typically take the readings from the first reflected pulse signal to reach the echo receiver terminal.

Subsequently, from the literature, the average headlight height from the ground of over 200 passenger vehicles from a survey was 82cm [14]. The position of the centre of the nameplate, which is typically the most protruded flat surface at the front of a vehicle, is usually about 5 cm below the mean headlight position.

Similarly, the red and green parking assistance indicators are placed at a distance above the ground at the average eye level of most male and female passenger vehicle drivers. Figure 3 gives an illustration of the vertical placement of sensors and indicators from ground level.

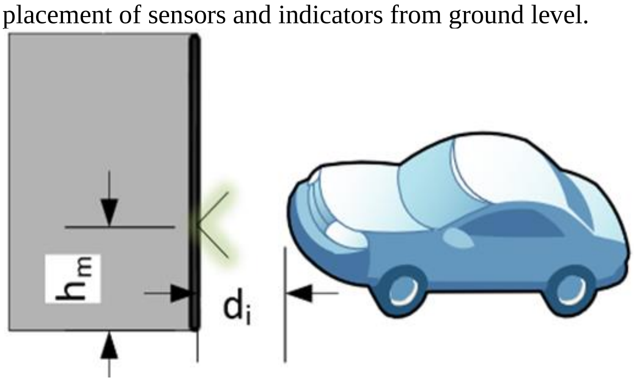


Fig. 3 Vertical placement of sensors and indicators from ground level

3.1.3. Circuit Design Specification

The choice of devices used for this sample design is based on the concept that each hub has many parking slots serviced by a wireless sensor network cluster. A single wireless sensor network cluster consists of a WemosMega with Wi-Fi capability, 12 HC-SR04 ultrasonic sensors and LED indicators for parking guidance. The sensor networks are then interfaced with an Internet-enabled Access Point to permit communication with the external server.

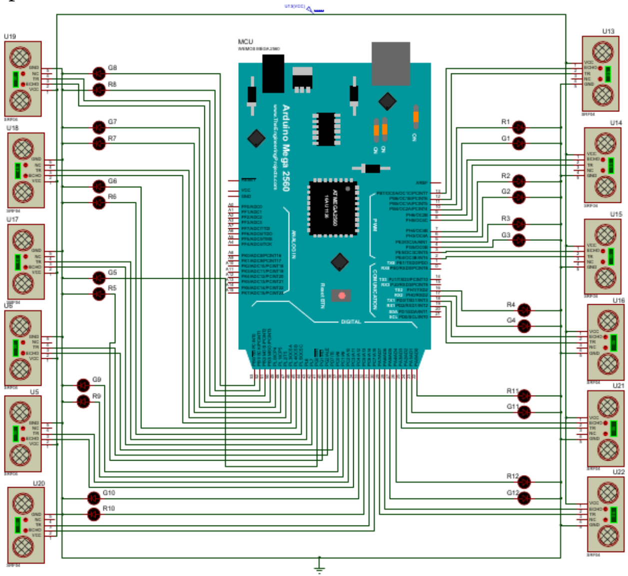


Fig. 4 Wireless Sensor Network (for a single hub)

3.2. Parking Slot Allocation Algorithm

The smart parking system is designed to guide users to a desirable parking slot based on their destination of interest. Thus, the procedure for parking slot allocation is given in Algorithm A. To identify the most suitable parking slot to be allotted to the user, a search process based on the flowchart in Figure 5 is used.

Algorithm A: Navigation to the parking lot

1: Open the Android application
2: Input Preferred Destination
3: Do
4: Query database to identify a suitable parking lot
5: Suggest the closest available parking lot to the driver
6: While (Until the user accepts the parking slot assigned)
7: Display the route to the selected parking lot
8: Mark the parking lot as assigned
9: If (A vehicle occupies the parking lot)
10: Mark the parking lot as occupied
11: Else
12: After 5mins, mark the parking lot as vacant
13: End if

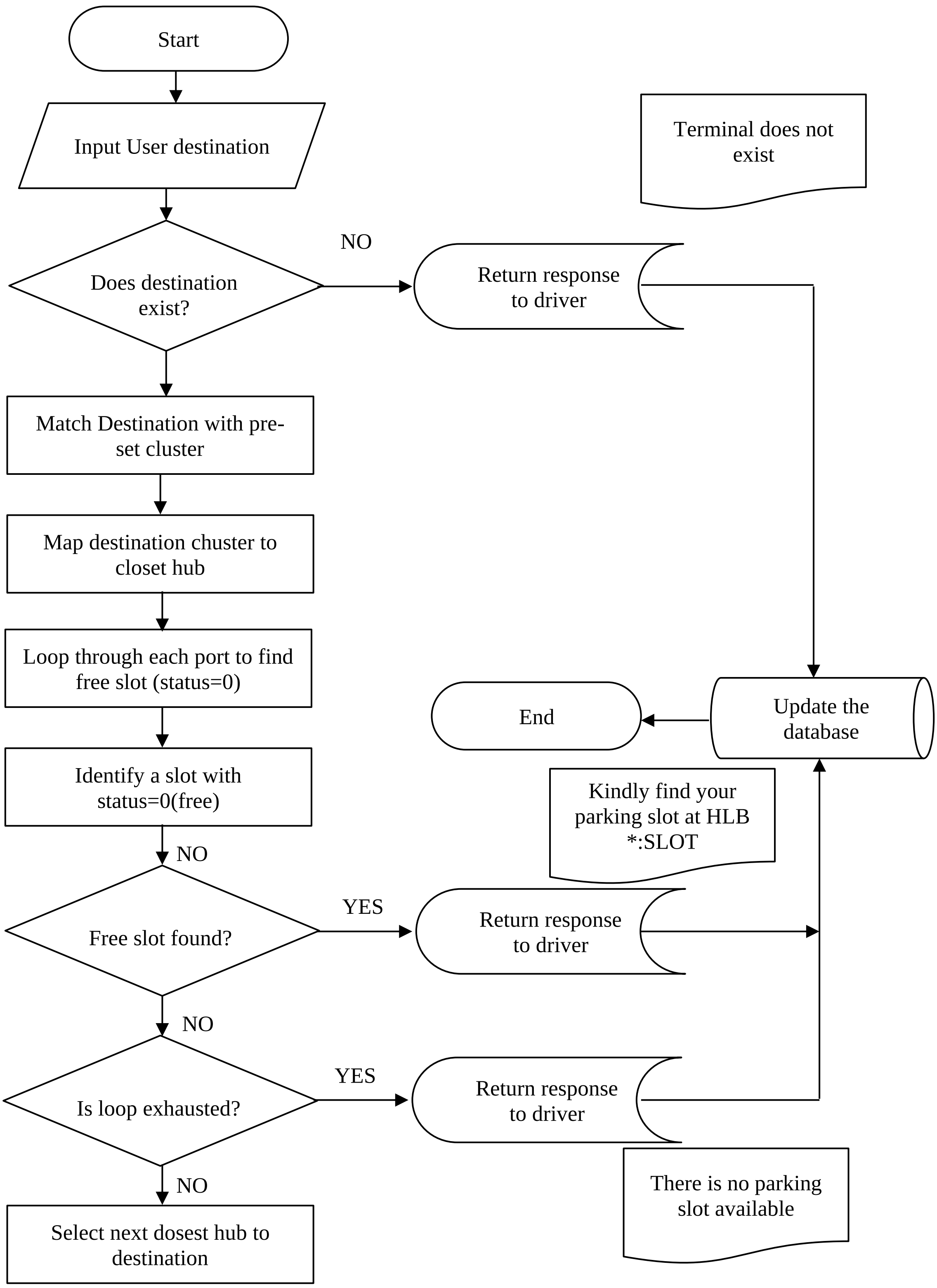


Fig. 5 Flowchart of the slot allocation algorithm

3.3. Route Selection Algorithm

The need to save commute time from source to destination necessitated the need for incorporation of the shortest path selection algorithm in optimal deciding which path the driver is advised to take to arrive at the allocated slot. The algorithm employed in achieving this is Dijkstra's algorithm.

3.3.1. Dijkstra's Algorithm

The algorithm was developed by Edsger Wybe Dijkstra (May 11, 1930 – August 6, 2002), a Dutch computer scientist from the Netherlands. Dijkstra's algorithm solves the single-source shortest-paths problem on a weighted, directed graph G = (V, E) for the case in which all edge weights are nonnegative. Dijkstra's algorithm maintains a set S of vertices whose final shortest-path weights from the source s have already been determined. The algorithm repeatedly selects the vertex u 2 V S with the minimum shortest-path estimate, adds u to S, and relaxes all edges leaving u. We use a min-priority queue Q of vertices in the following implementation, keyed by their d values [15].

3.3.2. Application of Algorithm in the Context of the Work

After the slot allocation algorithm has been used for selecting a slot for the driver, two parameters (Entry point and Destination hub) are passed to the shortest path selection function to return the optimal navigation route for the driver. The entry point (Gate 1, for example) serves as the source, while the allocated hub serves as the destination. Dijkstra's algorithm traverses through every node (turning point) in the parking area to compute the lowest distance coverage and the path to be followed.

3.4. Parking Assistance System

The parking assistance system has three main capabilities: to help users easily visually identify their assigned parking slots onsite, guide users to park appropriately within the parking slot, and alert users and the authorities when a vehicle is wrongly parked or an obstruction is placed in the way of a parking slot. These two features primarily make use of indicator lights to signal to the drivers as required.

To avoid the disappointment of users by meeting unauthorized vehicles parked in the slots assigned, a determent measure is proposed with the use of LED signal indicators. Three light colour states are proposed with the colours and signal meanings indicated in Table 1.

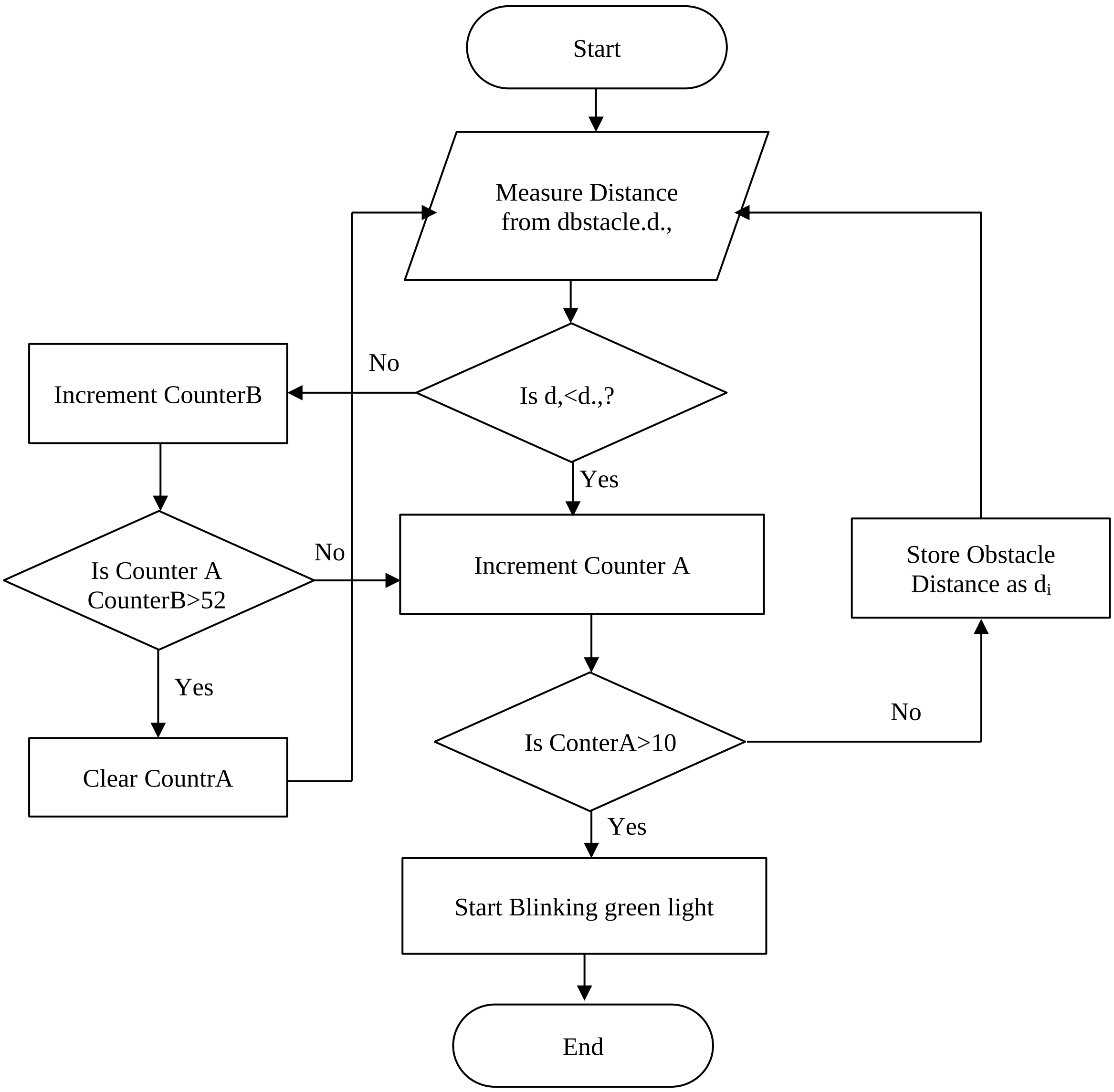


Fig. 6 Flowchart of vehicle arrival detection system

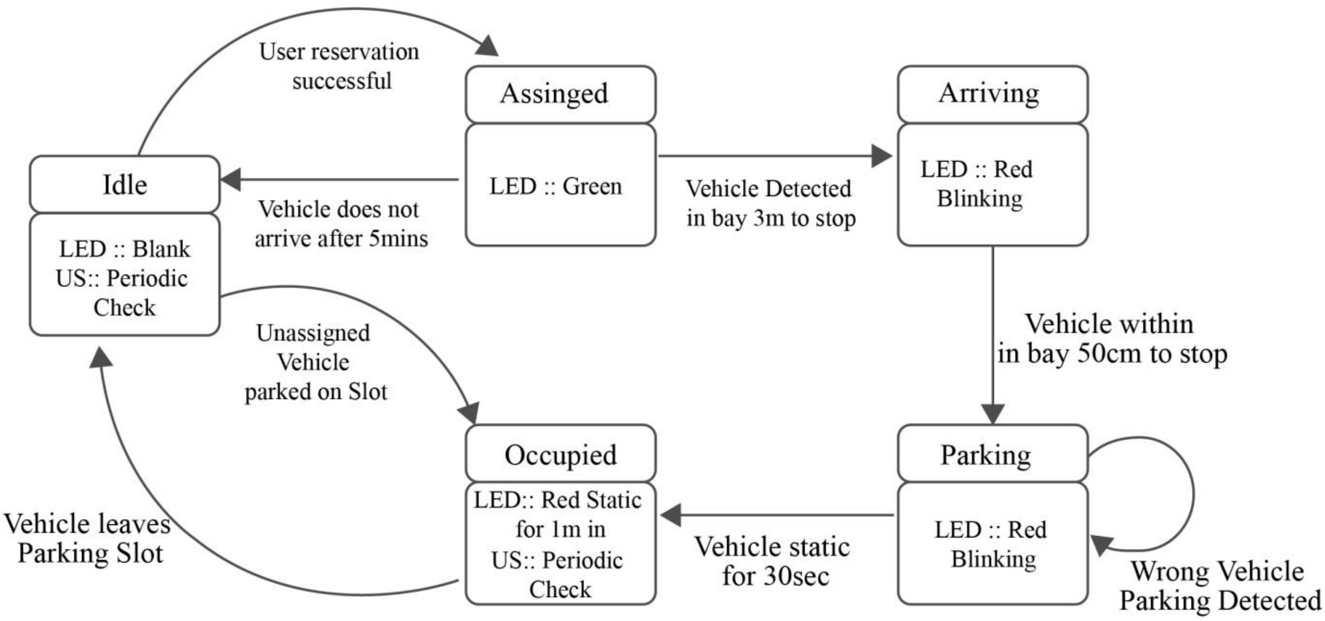


Fig. 7 State machine depicting system operation for a single parking slot

Table 1. Onsite parking assistance indicator colour codes

Colour	Meaning	Duration
Green	Assigned lot	For 5 mins after allocation
Red	Occupied lot	For 1 min after parking
Blank	Unassigned lot	Idle state

Figure 7 shows a diagram depicting the various state transitions on the parking slots and the consequently expected indicator behaviours. Every unassigned parking lot remains in idle mode but sends periodic ultrasonic signals to detect the random chance that a vehicle has been parked in the lot. The green light is lit when a driver accepts a parking lot via the mobile application. This would remain on for only 5mins, pending the time the vehicle arrives at the lot.

When a vehicle (obstacle) is detected within the parking lot, the green light begins to blink with 2 secs 50% duty cycle. The vehicle arrival detection algorithm is shown in Figure 6. This enables the system to decipher between when a vehicle normally drives into the parking lot and when an obstacle is simply detected due to passers-by or shopping carts, etc. When the vehicle gets close enough to the appropriate parking distance, the red light begins to blink for 2 secs 50% duty cycle. When the vehicle is confirmed parked close enough within the parking slot, the stable red light remains lit (100% duty cycle) for 1min.

If a vehicle is not correctly parked in an acceptable manner within a parking slot, a system to detect such has been considered in the smart parking assistance algorithm. In this condition, the red light continues to blink even when the vehicle is static until amendments are made, and a message would be sent to alert the admins if protracted.

For wrong parking detection, the system automatically recognises such a situation when the sensors on any two adjacent parking lots indicate the arrival of a vehicle concurrently, and the motion detected (decremental distance) on both sensors comes to a halt at the same time. This scenario indicates that the driver has parked the vehicle in an obstructive manner that transcends the use of a single parking slot, thereby encroaching into an adjacent slot. Other wrongly parked vehicle conditions that can be detected include vehicles not parked close enough to the terminus or parked too close to the terminus within the parking slot.

Figure 8 shows three examples of vehicles that are wrongly parked. In Figure 8 (a) & (b), the wrong parking of the vehicles does not hinder users of an adjacent slot from parking. However, in Figure 8 (c), it is practically impossible for another driver to use the adjacent slots. To a quantifiable degree of tolerance, the vehicles that are wrongly parked might not be detected, particularly those that might not necessarily have an adverse effect on the parking accuracy of a user who desires to park in an adjacent parking slot.

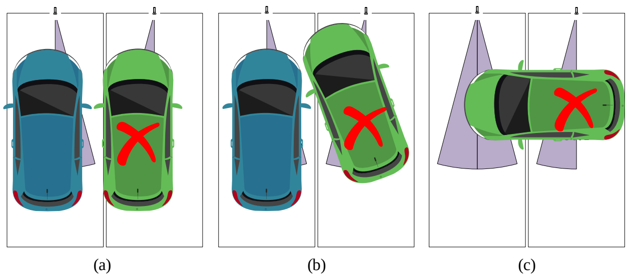


Fig. 8 Examples of wrongly parked vehicles (a) & (b) with a little adverse effect on the vehicles in the adjacent slots, (c) with an adverse effect on the vehicles in the adjacent slot

3.5. Mobile Application Platform

A mobile application was developed for the driver to aid the searching for available parking slots, as it is no doubt that mobile technology has a huge importance in everyday life.

The mobile application runs on the Android Operating System. The Android Operating System is a Linux-based mobile operating system designed primarily for touchscreen devices, cell phones and tablets. It is an open-source project that was initially developed by Android Inc. but is currently maintained and distributed commercially by Google.

The application was developed using the Kotlin programming language. Kotlin is a modern statically typed programming language that was designed with full interoperability with Java and the Java Virtual Machine (JVM). Kotlin was selected as the language of choice due to its conciseness, null-point safety and interoperability with Java.

The design architecture followed an Object-Oriented Design Pattern known as the Facade Pattern. The Facade Pattern is one of the Structural Design Patterns used to help client applications easily interact with the system [16].

4. Results

The various features of the smart parking system are evaluated to validate their potential to deliver the expected customer satisfaction. A case study is subsequently considered.

4.1. Sensor Validation

Due to the radial nature of the sensor trigger beam. However, it may be a rare occurrence; it is practically possible to park a vehicle wrongly without being detected, as shown in Figure 8. Based on the angular position of the vehicle within the parking bay, there is a maximum intrusion of a vehicle into the next parking slot without being detected.

The HC-SR04 ultrasonic sensor specification has a traveling range of 20mm to 4,000mm and a divergence angle of 15° according to the design specifications.

Validation of the sensor positioning would imply considering the standard parking slot sizes and verifying that the placement of an ultrasonic sensor would yield appropriate results. Table 2 shows some of the related values resulting from equation 3 and secondary data.

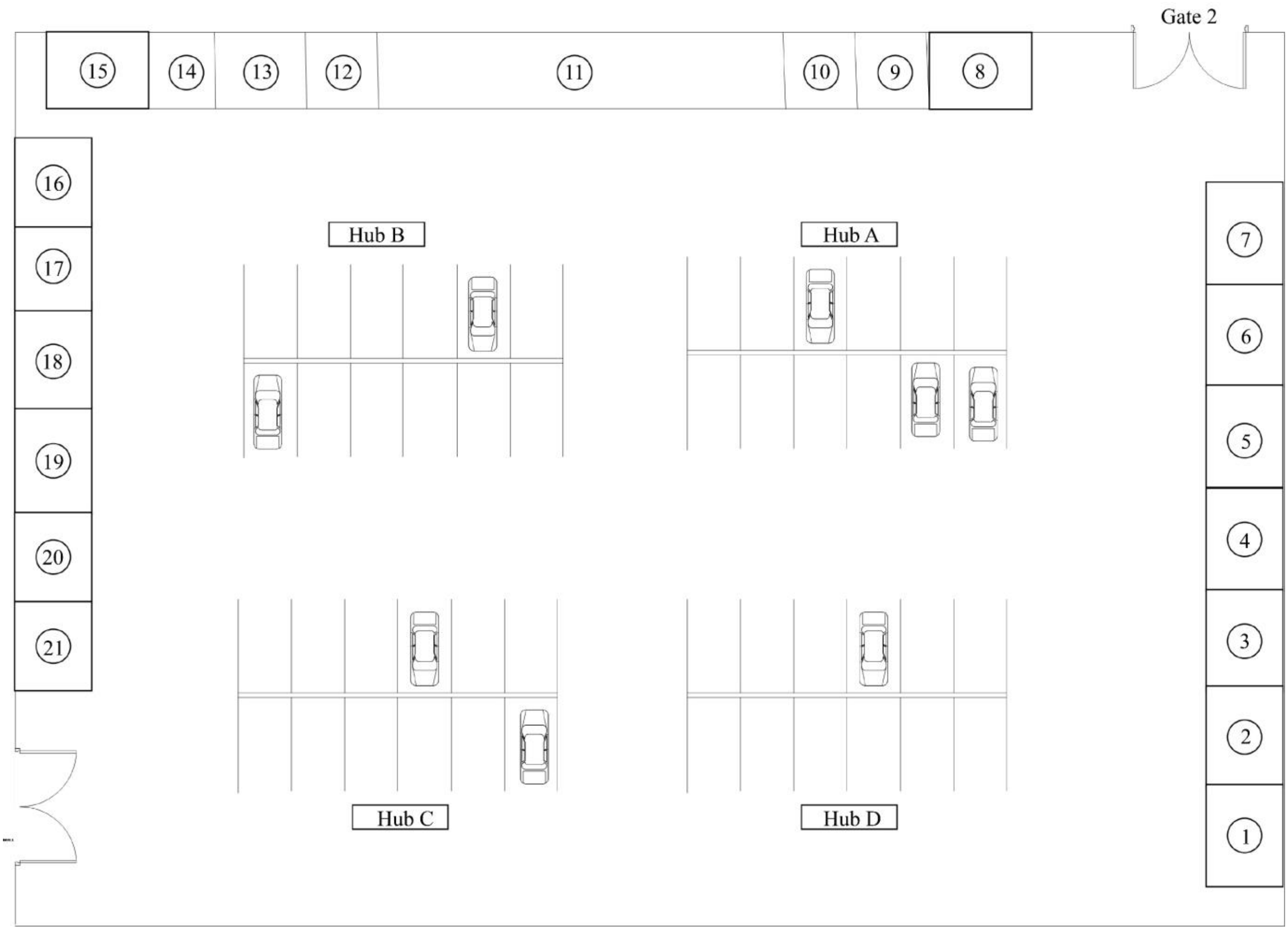


Fig. 9 Parking area physical layout

Table 2. Dimensions of sensor beam and standard parking slot & vehicle data

Width of Standard Parking slot, w_b	**Maximum width of Ultrasonic beam, w_m**	**Average height of Vehicle name plates**	**Minimum Hight of sensor above the ground**
259cm	207cm	77cm	103.5 cm

Table 2 shows that horizontal positioning criteria are met, such that placing the sensor at the centre of the parking slot would be appropriate. However, the vertical positioning criteria are not met, as placing the sensor horizontally at a height of 77cm might result in undesirable feedback. Hence, to compensate for the 36.5cm difference, the sensor is tilted by 5° above the horizontal plain. Thereby making the HC-SR04 ultrasonic sensor a viable device for this operation.

4.2. Case Study: Layout

A parking layout was needed to test and evaluate the proposed smart parking system. Several options of possible large parking lots were considered, and a quadrangle shopping mall formation was selected to help depict some of the major features of the smart parking system. An aerial view of the parking area is shown in Figure 9. The parking layout of choice involves parking module blocks (hubs A – D) of back-to-back parking slots with a 90-degrees angle of parking. The breakdown of the entities mapped out in the parking areas is also described in Table 3.

Table 3. Entities modelled in the parking area

S/N	**Entity**	**Units**	**Comment**
1	Stores	21	Desired destination of the driver
2	Clusters	7	Collection of stores for easy distance manipulation
3	Slots	48	Reserved parking area
4	Hubs	4	Collection of slots (12 slots each)
5	Gates	2	Point of entry into the shopping mall

The stores are the desired destinations of the drivers, in this case, individual shops of various sizes within the shopping mall. They are grouped into clusters for simplification of distance allocation such that stores within very close proximity to one another are grouped together as individual clusters in the system. The parking area consists of parking slots that are allocated to drivers after the desired destination is provided for reservation via a mobile application. These slots are also grouped into hubs for easy identification during routing. Entry points into the shopping mall are also captured as the optimal slot selection depends on the entrance gate into the parking lot. The parking area in view has two gates (entry points) which are worth considering for routing the vehicles after selection. For a two-way traffic flow permitted in all driveways within the parking lot, the model captures distances from entry points, parking areas and driver's destinations. Table 4 presents the mean distances of each shop cluster to each parking hub.

Table 4. Distance between clusters and parking hubs

Cluster	**Distance to Hubs (in meters)**			
	Hub A	Hub B	Hub C	Hub D
1	18.0	28.0	25.0	14.0
2	15.0	25.0	28.0	20.0
3	13.0	20.0	30.0	24.0
4	15.0	15.0	26.0	26.0
5	20.0	13.0	28.0	30.0
6	25.0	15.0	20.0	28.0
7	28.0	18.0	14.0	25.0

4.3. Case Study: Route Mapping

A graph representing physical entities using vertices and edges is used to model the parking area. The distances are represented as weighted edges on the graph while turning points and destination hubs are represented as vertices or nodes.

Figure 10 shows the graph representation detailing the nodes and edges of the parking area. Table 5 gives the matrix of the graph. The Dijkstra algorithm discussed in Section 3.3 uses the matric to compute the shortest path that can be taken from the entry point to the parking slot from a list of possible routes.

Table 5. Weighted graph matrix of parking area

	n1	**n2**	**n3**	**n4**	**n5**	**n6**	**n7**	**n8**	**n9**
n1	0	0	0	15	0	0	0	0	0
n2	0	0	0	0	15	0	0	0	0
n3	0	0	0	0	0	15	0	0	0
n4	15	0	0	0	0	0	15	0	0
n5	0	15	0	0	0	0	0	15	0
n6	0	0	15	0	0	0	0	0	15
n7	0	0	0	15	0	0	0	0	0
n8	0	0	0	0	15	0	0	0	0
n9	0	0	0	0	0	15	0	0	0
G1	5	0	0	0	0	0	0	0	0
G2	0	0	0	0	0	0	0	0	5
A_{1-6}	0	0	0	0	0	0	0	10	10
A_{7-12}	0	0	0	0	10	10	0	0	0
B_{1-6}	0	0	0	0	0	0	10	10	0
B_{7-12}	0	0	0	10	10	0	0	0	0
C_{1-6}	0	0	0	10	10	0	0	0	0
C_{7-12}	10	10	0	0	0	0	0	0	0
D_{1-6}	0	0	0	0	10	10	0	0	0
D_{7-12}	0	0	10	0	0	0	0	0	0

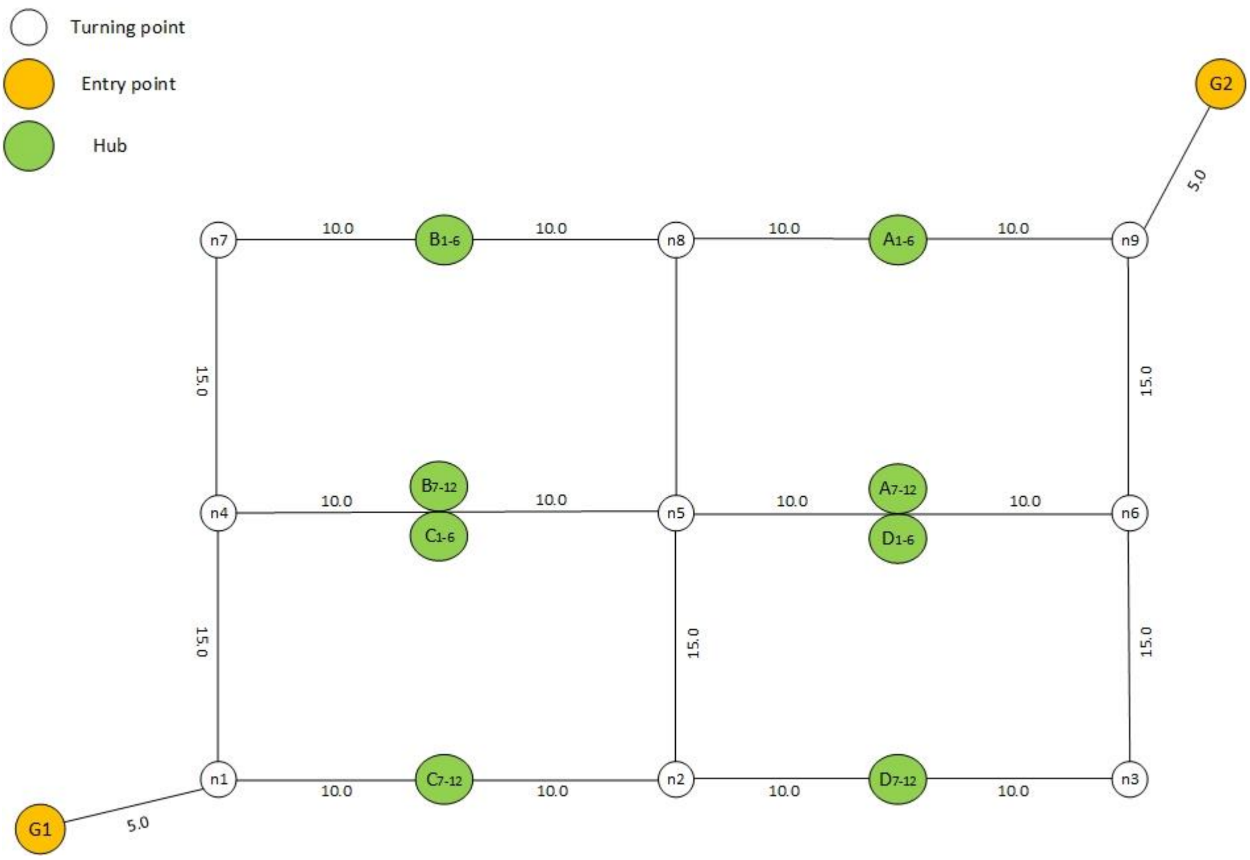
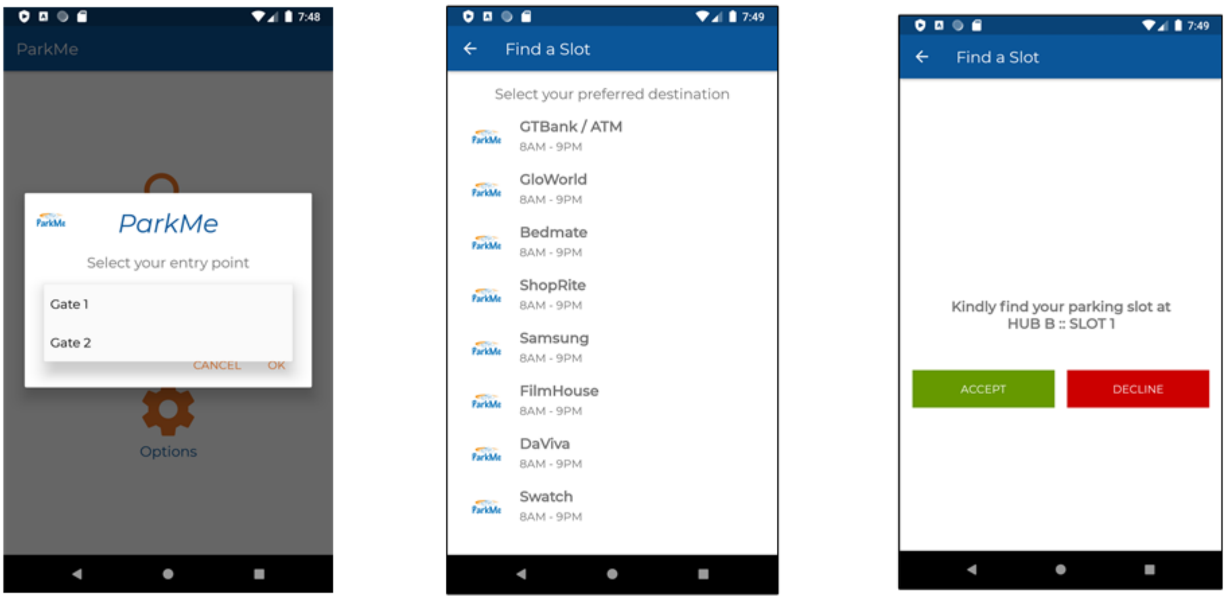


Fig. 10 Graph representation of parking area



(a) Select entry point **(b) Select the desired store** **(c) Accept or decline allocated slot**

Fig. 11 Mobile application user interface

4.4. Parking Scenarios

A test was carried out for a scenario of a hypothetical busy day in the shopping mall, in which customers come in vehicles to the mall to visit various stores. The scenario assumes that all parking slots were empty at the initial stage of the test and filled at the end of the test session. Also, all vehicles are assumed to comply with the parking allocation given, and no vehicle is expected to leave the parking lot within the period of the test. Subsequently, the parking slot allocations are shown in Appendix A: Table 6 for sample vehicles. It can be observed that at some points when the hubs closest to the user's destinations are occupied, the nearest available hubs are allocated considering the gate of entry. Finally, when all 48 slots are occupied, the remark returned to the user is that no parking slot is available.

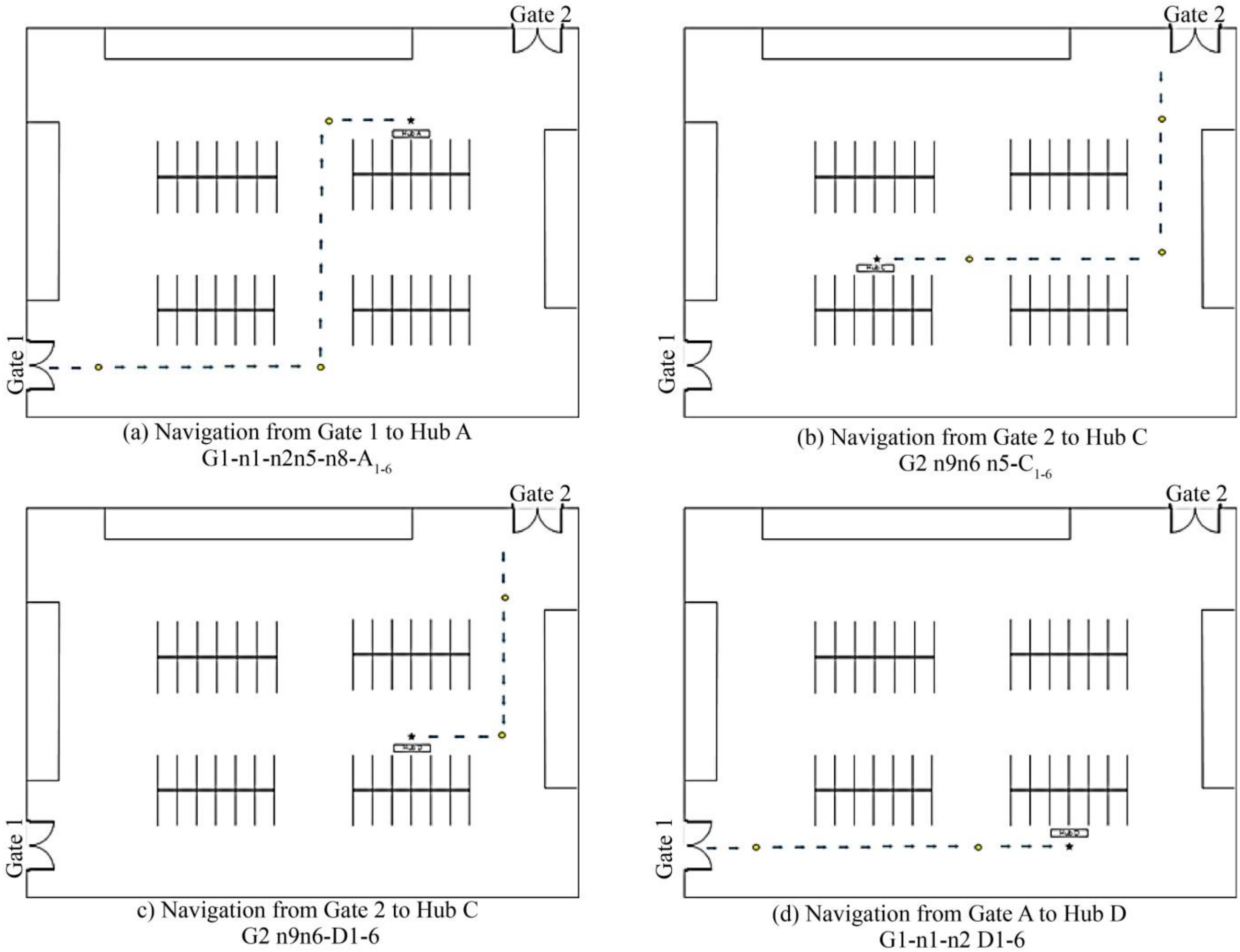


Fig. 12 Sample navigations rendered on the mobile application

4.5. Mobile Application

Some of the responses from the mobile application were captured to show the interaction between the drivers and the parking management system. Figure 11 shows the graphical steps a driver takes on the mobile application in requesting a parking slot. Upon accepting the allocated slot, the parking management system renders the navigation on the device, as shown in Figure 12. The system also informs the driver if there is no available parking space.

4.6. Potential Time, Fuel and CO Savings

The amount of CO emitted can be estimated from the amount of fuel spent while driving the vehicle. Due to the automated allocation and navigation system introduced, an estimate of the CO emission savings can be made for the significant reduction in time spent by drivers to locate a parking slot. We assume that, on average, 50% of vehicles in the car park might need to reroute in search of a vacant parking slot close to their destination in the absence of the smart parking system. Such a search can be estimated to involve hypothetically covering a distance equivalent to navigating halfway around a single parking hub. Consequently, the extra distance covered to navigate to a vacant parking slot can be estimated from the known parking lot dimensions.

Given that the amount of CO emitted is a function of several stochastic conditions, including vehicle loading, driving speed, use of air conditioning, ambient temperature and a couple of other variable factors, it is rather difficult to evaluate the CO emission. However, making use of statistical data from the U.S. Environmental Protection Agency, the average CO emission rate for the calibre of lightweight passenger vehicles expected in the parking lot was 2.449 g/Km per vehicle in the year 2018 [17].

Thus, assuming an average of 72 vehicles have to undergo the reroute search process in a day for the non-smart parking scenario, then with each vehicle driving an extra 25m, the total additional emission from all the vehicles within the parking lot in a day will be 4.4082g. Hence, operating the smart parking system has the potential of saving 1.609Kg of CO emission in a year.

5. Conclusion

The smart parking solution proposed in this paper showcases a convenient means for vehicle owners to identify available parking spaces close to their desired destination and the shortest route to follow from their point of entry using Dijkstra's algorithm. Clients use an easy-to-use mobile application to request allocation to parking slots, and a map with a route to the assigned slot is returned on the client's app. Subsequently, ultrasound sensors are used to sense vehicle absence, arrival and departure within a parking slot. Concurrently, a novel application of ultrasonic sensors in parking guidance systems is proposed, in which generic light indicators are used to guide the drivers to park properly within their slots without trespassing to another parking slot or parking too far or too close to the curb. From the case study scenario of a double entry point parking lot with four parking hubs, it is observed that not only do clients enjoy the satisfaction of parking as close as possible to their desired destination, but the navigation from the point of entry to the parking hub also has the potential of saving 1.609 Kg of CO emission in a year for a 48 slots capacity parking lot.

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Appendix A

Table 6. Parking slot allocation and route suggestion scenarios

Test No	User	Entry Point (Gate)	Preferred Destination	Closest Hub	Distance to destination (m)	Slot Allocated	Shortest Route Taken	Remarks
1	A	1	SHOPRITE	Hub A	18.0	Slot 1	G1 - n1 - n2 - n5 - n8 - A_{1-6}	Available slot allocated
2	B	1	SHOPRITE	Hub A	18.0	Slot 2	G1 - n1 - n2 - n5 - n8 - A_{1-6}	Same destination, same hub but a different available slot
3	C	2	SHOPRITE	Hub A	18.0	Slot 3	G2 - n9 - A_{1-6}	Next available slot closest to the destination
4	D	1	NIKE	Hub B	15.0	Slot 1	G1 - n1 - n4 - n7 - B_{1-6}	Closest available slot
5	E	2	SWATCH	Hub B	13.0	Slot 2	G2 - n9 - n8 - B_{1-6}	Closest available slot
6	F	2	STUDIO 24	Hub C	14.0	Slot 1	G2 - n9 - n6 - n5 - C_{1-6}	Closest available slot
7	G	1	STUDIO 24	Hub C	14.0	Slot 2	G1 - n1 - n4 - C_{1-6}	Same destination, same hub but a different available slot
8	H	2	ATM	Hub A	13.0	Slot 4	G2 - n9 - A_{1-6}	Closest available slot
9	I	1	BUKKA HUT	Hub D	14.0	Slot 1	G1 - n1 - n2 - n5 - D_{1-6}	Closest available slot
10	J	2	BUKKA HUT	Hub D	14.0	Slot 2	G2 - n9 - n6 - D_{1-6}	Same destination, same hub but a different route
11 to 47	All but one slot filled							
48	H	2	SHOPRITE	Hub D	26.0	Slot 1	G2 - n9 - n6 - n3 - D_{1-6}	The only available slot left (The algorithm is non-functional here)
49	I	1	KFC	Hub D	15.0	NONE	NONE	No parking slot is available