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Development and Implementation of a Smart Parking Spot Allocation System Based on the User's Category and Priority using Verilog HDL

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Abstract: Finding parking spots for automobiles is a major issue in many large and congested cities. Usually, drivers lose time searching for parking spots, especially during peak hours, which increases traffic congestion and makes drivers frustrated and annoyed. Large building parking areas could also become dangerous to women, pregnant women, and the elderly, as several criminal cases in the parking area, were reported. In this project, a prototype of a smart parking spot allocation system based on the user's category and priority was developed. The choice of user categories is people with disabilities (OKU), pregnant women/elderly, women, and normal users. The highest priority is assigned to OKU, followed by pregnant women/elderly, followed by women and the lowest priority is assigned to normal users. The parking spots for the highest priority category are placed near building entrances such as mall entrances. The controller for the automatic parking spot allocation system was developed using Verilog HDL code and the prototype was implemented on FPGA DE2-115. The controller is programmed to process the user's category which is selected by the user at the second entrance and assign a specific parking spot number according to the category's priority. The prototype was tested with multiple parking spots condition with different user inputs for different user categories. The system was able to allocate parking spots based on the user's category depending on the parking spot available for the selected category with 75% out of 12 tests correct. However, all 12 tests, or 100% recorded accurate allocation based on the expected output of the system design. In a conclusion, this proposed system would be able to cater to the issue of finding parking spots hence directly avoiding traffic congestion and frustration among users. In addition, this system can indirectly reduce crime cases in the parking area due to parking spaces that prioritize categories of users needing to be parked near the entrance.

Keywords: Parking spot allocation, user category, user priority, Verilog HDL, FPGA

1. Introduction

The massive expansion in the number of automobiles in metropolitan areas, along with traffic, has become a major cause of parking-related issues [1]. Instead of being in a good mood in the automobile, this situation made the drivers even more stressed and frustrated. Furthermore, for many women and girls around the world just passing through public places cause great anxiety [2]. These are sites where criminal activity and accidents are common. A smart parking system can allocate a useful parking spot while also providing real-time parking spot information that notifies customers of available parking spots and helps them in finding adjacent parking spots [3]–[5].

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Several publications [3]–[6] presented the use of the Internet of Things (IoT) in the development of their real-time smart parking system monitoring. The smart parking system presented by Elakya et al. [3] proposed to allocate an effective parking spot as well as deliver real-time parking spot information. This paper used IoT which gives wireless access to the system, allowing the user to keep track of the parking area's availability, also the user receives a notification with the parking information, and RFID technology is employed. This research project can reduce traffic congestion and the time and effort users spend looking for parking spots, as well as car theft. This paper also minimizes the overall fuel energy consumed by the vehicle during the search the parking as reviewed by Elakya et al. [3].

Lookmuang et al. [4] proposed the same objective as Elakya et al. [3] which is to design a real-time smart parking system that alerts users to available parking spots with additional functionality that can assist users in locating nearby available parking spots. Lookmuang et al. [4] and Sadhukhan et al. [5] used computer vision to detect vehicle/registration plate images in their smart parking system. For large buildings such as shopping complexes, instead of parking spot monitoring, the parking spot allocation process is also important for user satisfaction. However, several research focusing on parking spot allocation is still small compared to parking space monitoring. Table 1 summarize published research related to the smart parking system. As tabulated in the table, most of the smart parking systems were focusing on parking space monitoring (most researchers use IoT) rather than focusing on parking space allocation. Arduino, Raspberry Pi3, and Field Programmable Gate Arrays (FPGA) became the most preferred implementation to suit their system design.

Table 1 - Previous works on smart parking system

No.	Author	Year	Research Title	Smart Parking Process	Implementation	Description
1	R. Lookmuang et. al. [4]	2019	Smart Parking Using IoT Technology	Monitoring, Allocation, and Payment	Raspberry Pi3	The system uses computer vision to detect the plate number of the vehicle
2	R. Elakya et. al. [3]	2019	Smart Parking System using IoT	Monitoring	Arduino	The system uses an ultrasonic sensor to detect car availability and RFID Tag as a pass to view the parking status
3	M. Zou et. al. [7]	2019	Optimization of Parking Space Allocation for Automated Parking System of Paternoster Type by Genetic Algorithm	Allocation	Simulation: Genetic Algorithm	The system uses a mathematical model for allocation prosses of APS paternoster-type parking area
4	S. S. Devi et. al. [8]	2020	Car Parking System Using FPGA	Monitoring and assisting	FPGA Spartan 6	The system uses an ultrasonic sensor to detect car availability
5	Y. Agarwal et. al. [9]	2021	IoT-based Smart Parking System	Monitoring	Arduino	Use ultrasonic sensor to check parking status and RFID for authentication
6	M. Kumar et. al. [10]	2022	Design and Implementation of a Secured Car Parking System using FPGA	Security at the entrance (user enters password)	Arduino Uno (IoT) FPGA Artix 7 Series	Use the keypad at the entrance of the parking area, and open the gate if the password corrects
7	K. J. Yong et. al. [11]	2022	Design and implementation of embedded auto car parking system using FPGA for emergency conditions	Driver Monitoring in Vehicle	FPGA	Detect the driver’s condition and perform specific tasks such as warning the drivers
8	R. R. Venkataraman et. al. [12]	2022	Multi-Car Parking System Using Verilog	Monitoring	Simulation: Xilinx Vivado ISE 20.1	The system reads the correct username and password and allows the user to enter parking for 4 parking spots

FPGAs were chosen for the system development due to several reasons. A reconfigurable FPGA is an efficient technique to construct a design because FPGA provides a compromise between general-purpose processors and ASIC [13]. The greatest benefit of FPGA-based designs are more flexible, programmable, and reprogrammable, allowing for trial and error, but do not have a fixed program code or parallel processing, cost efficiency, and multiple input/output capability that can be designed by a developer for different application platforms after production [14]–[17]. An FPGA-based design software system also can be quickly upgraded. FPGA, on the other hand, is well suited to time-critical systems since each task on the FPGA hardware can run a separate set of logic at the same time which is also known as parallel processing [14], [18]-[19]. Because it can provide high-speed, low time-to-market, good cost-performance, and availability of specialized intellectual property, FPGA is one of the preferred implementation platforms in many industry sectors (IP) [14]–[17].

In this work, we present a system for parking spot allocation system that can assign the parking spot to the user to the nearest available parking spot depending on the user's category and priority. The assigned process is performed at the parking entrance. The parking area is divided into four categories; pregnant women/elderly, women only, persons with disabilities (OKU), and normal parking. At first, users have to select their category to allow this system to perform the allocation process. After the user has selected the categories, the system will assign the user to the nearest available parking spot and the automatic bar gate will open.

The goal of this work is to design a Smart Parking Spot Allocation System Controller for a single-level parking area utilizing the Quartus Prime Lite Edition tool [20] in Verilog HDL and test bench code. Next, using the Questa Intel Starter FPGA Edition tool [21], this research aims to verify design functionality using timing waveform. The hardware design functionality is verified on an FPGA Altera DE2-115 board as a prototype implementation. FPGA is chosen as the prototype implementation due to its reconfigurability. The reprogrammable feature allows the redesign process to be done whenever required. For the prototype implementation, the onboard input-output devices on FPGA such as LEDs, LCD and push buttons are ready to be used. Only some additional external input-output devices such as ultrasonic sensors, motors, and buzzers need to be added and thus can minimize the course of the prototype implementation.

2. Methodology

Project design, software design verification, and hardware design verification were the main tasks of this project. For this project, tools Quartus Prime Lite Edition and Questa Intel Starter FPGA Edition were utilized, as well as an FPGA Altera DE2-115 board used for the hardware implementation.

2.1 Design of Smart Parking Spot Allocation System

This "Smart Parking Spot Allocation System" is designed for a single-level parking area with twelve parking spots as the prototype implementation. This design can be further expanded to multi-level with larger parking spots for real implementation. For the prototype implementation, two parking spots were allocated for each pregnant woman/elderly and OKU user. While three parking spots were allocated for women users and the balanced five parking spots were assigned to normal users. Before the car can enter the parking area, there are two automatic bar gates. The first automatic bar gate will close automatically when all the parking spots have been filled, preventing cars from entering the parking area to avoid frustration in finding unavailable parking spots. At the second automatic bar gate, there is a selection panel for users to choose their category and obtain the allocated parking spot based on their category. The input and out components on the selection panel are shown in Fig. 1. Users can choose four options of the category of women only (WO), pregnant women/elderly (PWE), people with disabilities (OKU), and normal parking (NP). The choices of category in the selection panel are labelled as H.

The three seven segments labelled as C are used to display the number of assigned parking spots. The other seven segments labelled as D are used to display the user's category that was selected by the user. The liquid crystal display (LCD) is used to display information or instruction to users (labeled as B), and the automatic bar is labeled as A. The LEDs (labelled as E, F, and I) and the buzzer (labelled as J) are used as indicators. While the IR sensor for car detection at the automatic bar is labelled as G.

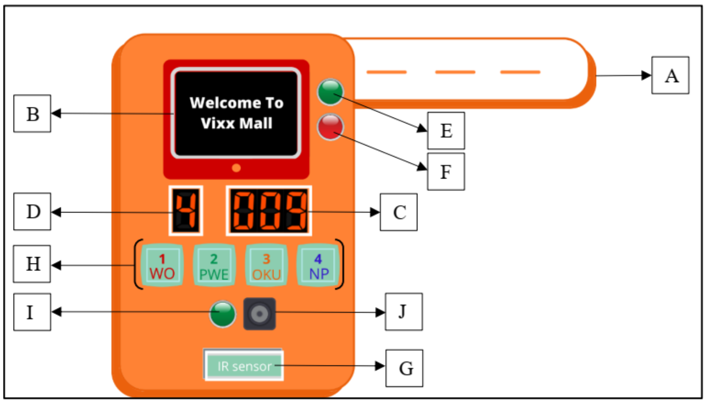


Fig. 1 - The position of the input and output components on the selection panel located at the second automatic bar gate

Fig. 2 depicts the parking area layout, which displays the parking spot arrangement for each category of OKU, pregnant women/elderly, women, and normal parking categories. The parking spots for OKU, pregnant women/the elderly, and women are all located near the mall entrance (considering a parking area for a shopping mall) based the priority. Table 2 summarizes the level of priority for each category in which the highest priority was assigned to OKU and the lowest priority was assigned to a normal user. The priority setting was realized by assigning specific parking spots near the mall entrance for the category with the highest priority. To identify whether a parking spot is empty or not, several IR sensors equivalent to the total number of parking spots were installed at the parking spot connected to the Altera Board DE2-115.

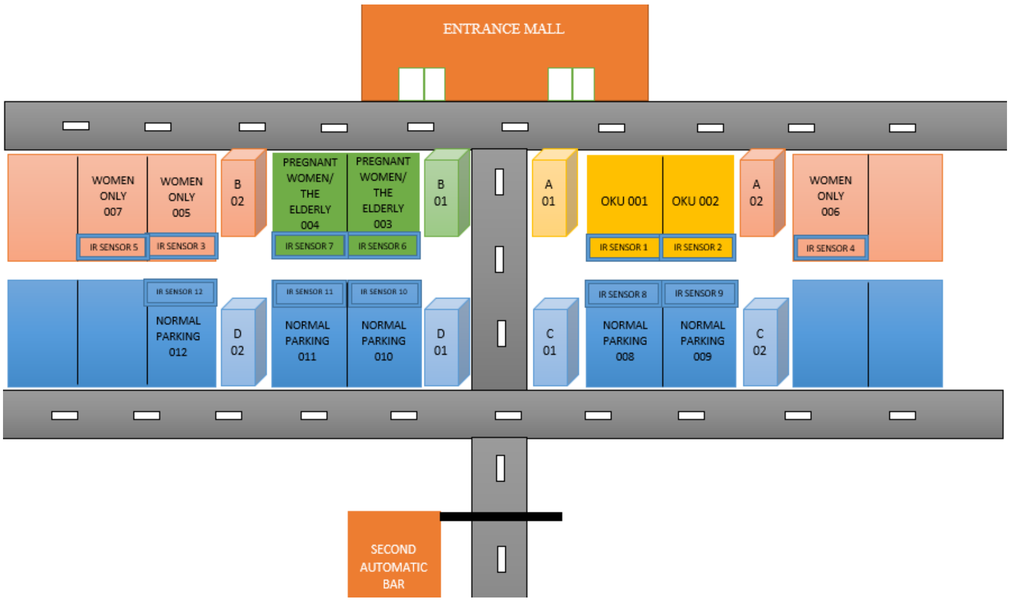


Fig. 2 - Parking area layout for the prototype implementation with the category's arrangement is based on priority

Table 2 - Level of priority for each user's category

User's Category	Priority Level
People with Disabilities (OKU)	1
Pregnant Women / Elderly	2
Women	3
Normal	4

The block diagram of the parking spot allocation system is shown in Fig. 3. This project consists of three inputs which are push buttons, slide switches, and IR sensors. This push button serves as an input for the user to select their category. The presence of vehicles at the second automatic bar is detected using an IR sensor, while the presence of vehicles at the parking spots is also detected using IR sensors. The slide switches are used as the reset and seven-segment enable. The system has five outputs. The outputs are a 16×2 liquid crystal display (LCD), seven segment display a red and green light emitting diode (LED), a buzzer, and a servo motor. The 16×2 liquid crystal display (LCD) is used to show the user the information/instruction message, while the seven-segment display is used to display the number of the assigned parking spot based on the user's input (category).

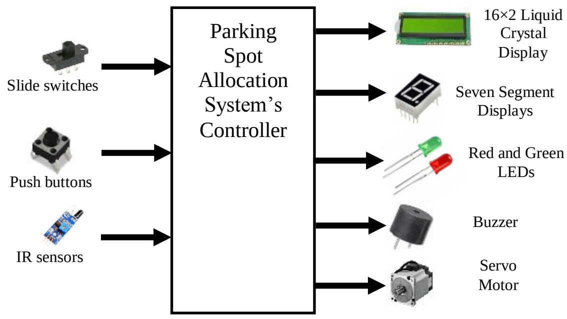


Fig. 3 - Block diagram of the smart parking spot allocation system

The green and red LED near the automatic bar on the selection panel (labelled as E and F) use are d to indicate the status of the bar gate. The green LED illuminates when the bar gate is opened, and the red LED illuminates when the bar gate is closed. The green LED at the bottom side of the selection panel (labelled as I) and the buzzer is used to notify the user that any button has been pressed. The green LED illuminates and the buzzer produces a beep sound when any push button is pressed. The barred gate is opened and closed using a servo motor.

2.2 Verilog HDL Design for Smart Parking Spot Allocation System Controller using Quartus Prime Lite Edition

The controller for the Smart Parking Spot Allocation System is designed using Verilog HDL code and the tool used is Quartus Prime Lite Edition. The internal architecture of the system is depicted in Fig. 4. The design was divided into six submodules comprising clock division, LCD control, push-button control, seven-segment control, main control, and automatic bar control.

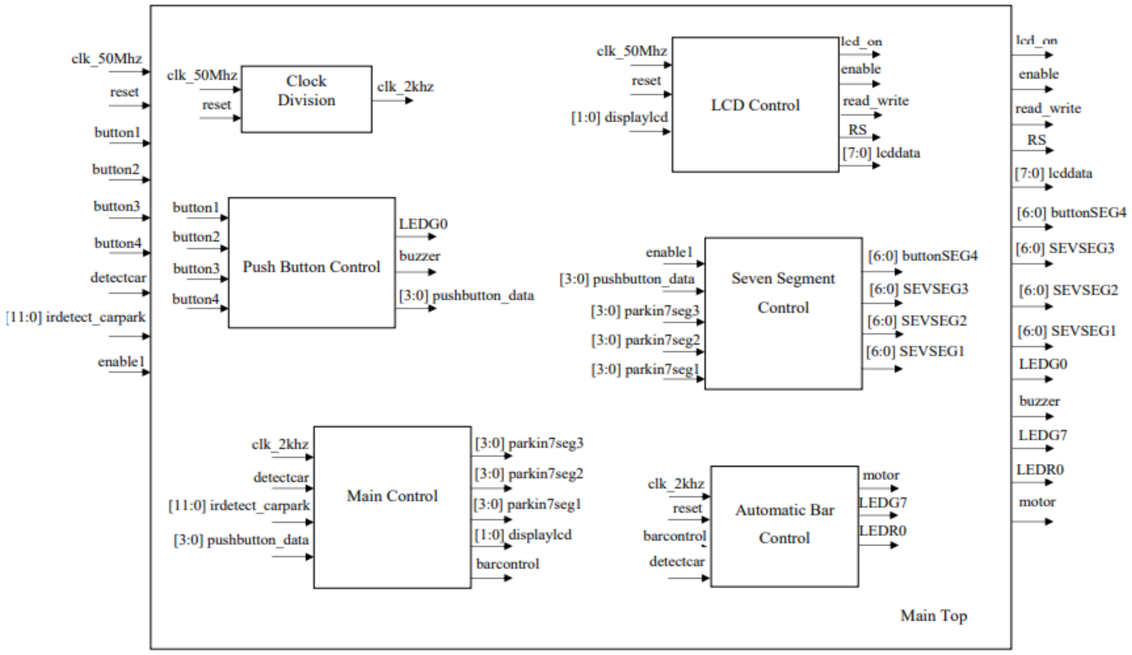


Fig. 4 - The internal architecture of the smart parking spot allocation controller

The flow of the system is portrayed in Fig. 5. The system begins with a welcome message displayed on the LCD (Example of welcome message: “Welcome to VIXX Mall”). If an IR sensor detects the presence of a car, the system will read the availability of all twelve parking spots using IR sensors. If a free parking spot is unavailable, the LCD will display “Sorry No Parking”. Otherwise, the LCD will display “Choose Type of Parking”. If the IR sensor detects no car, the LCD will continuously display the welcome message. When the LCD “Choose Type of Parking”, the user must select the type of parking based on the user’s category using the push buttons. The choices of push-button are either button 1 for women or button 2 for pregnant women/the elderly or button 3 for OKU or button 4 for a normal user. The allocation process for each category is performed separately depending on the availability of parking spots for each selected category.

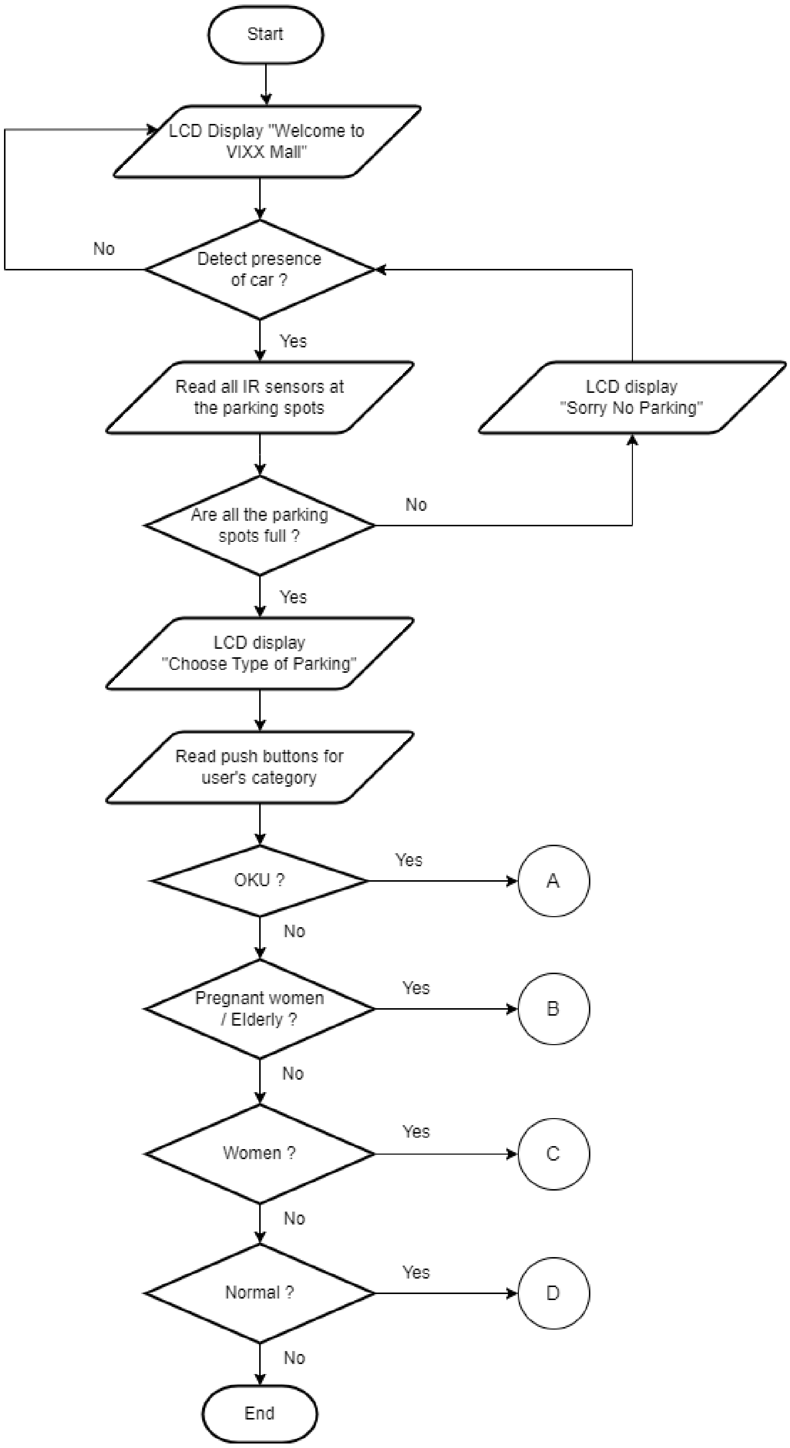


Fig. 5 - Main flowchart of the smart parking spot allocation system

For each category, the system will assign a parking spot based on the nearest parking spot to the mall entrance. The flowcharts for each category were attached in Appendix A. The system will check the availability of the nearest parking spot first, followed by the second nearest spot, and so on. The system will display the assigned parking spot number on the seven segments. If all the parking spots for the selected category are unavailable, the system will switch to the normal parking spot option. In some cases, the user from the category OKU, pregnant women/elderly, and women are willing to park their vehicles in normal parking areas due to a limited number of parking for their category.

For the automatic bar control operation, the flowchart is also attached in Appendix A. If the user successfully obtained their assigned parking spot number, the system would send a signal to the bar control module, enabling the bar control status to change to active "high," and the green LED lights up. The automatic bar will immediately open using a motor. The IR sensor at the automatic bar was then read by the system. If the IR sensor detects that the car has not moved yet, the system will still open the bar. If the car has moved, the red LED light will illuminate, signaling the automatic bar to close.

2.3 Software Design Verification for Test Bench using Questa Intel Starter FPGA Edition

The designed system is compiled, and the Questa Intel Starter FPGA Edition tool is used to verify the software design functionality using a test bench code. The test bench is used to provide the input signals to the designed system and the functional verification is observed using a timing diagram. All submodules were initially verified for their functionality using their test bench. All submodules were then instantiated in one top module as the system's controller and the functionality of the system's controller was verified using the top module test bench.

2.4 Hardware Design Verification using FPGA Altera DE2-115 Board

After successfully verifying the software design functionality using Questa Intel Starter FPGA Edition, the system is implemented onto the FPGA Altera DE2-115 board to evaluate its hardware functionality. Pin assignment, programming, and configuring the FPGA device are the processes required for hardware design verification. The configuration data is sent from the host computer to the board via a USB cable using USB-Blaster.

3. Results and Discussion

This section presents a summary of the result obtained after compiling the design of the Smart Parking Spot Allocation System's Controller using Quartus Prime Lite Edition, Questa Intel Starter FPGA Edition and after implementing the design on the FPGA Altera DE2-115 board.

3.1 Functional Software Verification using Quartus Prime Lite Edition and Questa Intel Starter FPGA Edition

After performing the compilation of the parking spot allocation system's controller design using Quartus Prime Lite Edition, the internal design architecture for the controller was observed in the RTL Viewers as shown in Fig. 6. All six submodules we successfully instantiated, and the connection between all submodules shown in RTL Viewers are correct as what has been planned as in Fig. 4.

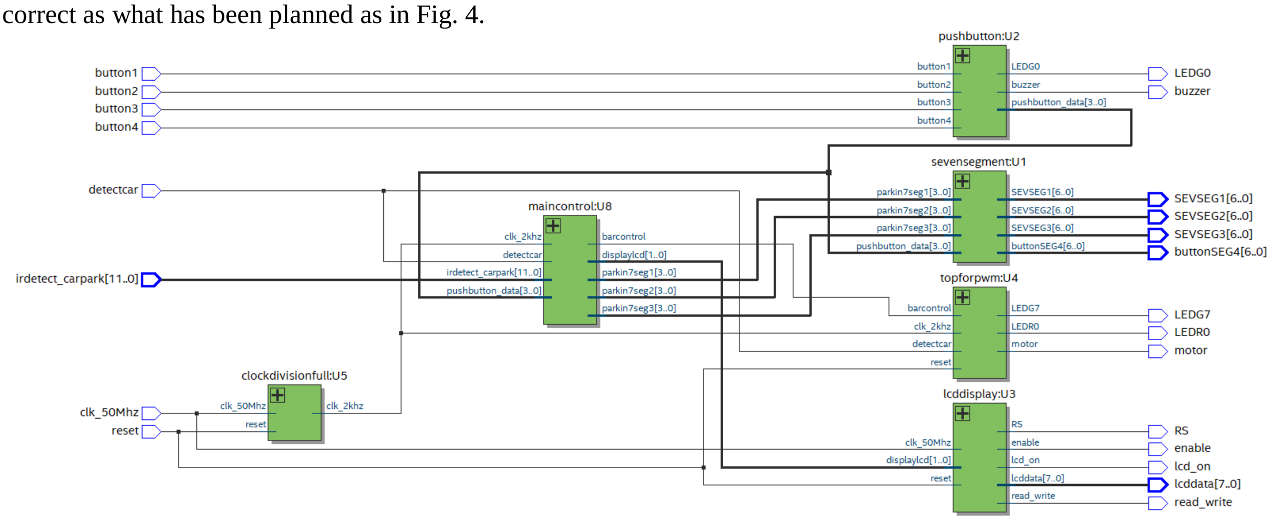


Fig. 6 - RTL viewers for the smart parking spot allocation system's controller

Fig. 7 shows the timing diagram for the controller (using Questa Intel Starter FPGA Edition) at a condition where no car is detected at the automatic bar gate (detectcar = 1), and the LCD displayed the welcome message "Welcome to Vixx Mall". Fig. 8 shows the timing diagram for a condition when a car is detected at the automatic bar gate (detectcar = 0), but all the parking spots are fully occupied, and the LCDs "Sorry No Parking". Signal irdetect_carpark is a twelve bits signal connected to the twelve IR sensors that detect the availability of the parking spots. Signal "0" indicates an unavailable parking spot while signal "1" indicates an available parking spot.

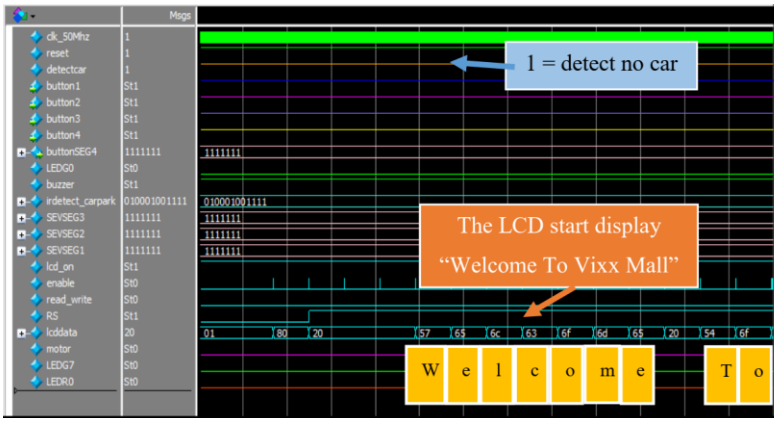


Fig. 7 - The timing diagram shows when no car is detected, the LCD a welcome message 'Welcome To Vixx Mall'

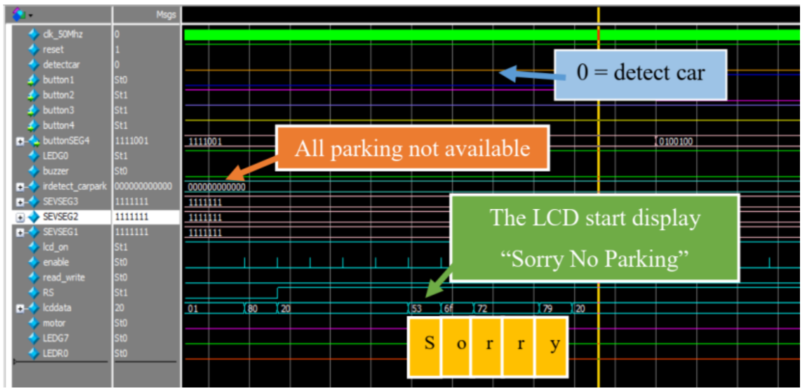


Fig. 8 - The timing diagram shows, when a car is detected the parking lot is fully occupied, and the LCD 'Sorry No Parking'

When a car is identified at the automatic bar (detectcar = 0) and parking spots are available (from irdetect_carpark signal), the LCDs "Choose Type of Parking," as shown in Fig. 9. By using the push button, users must select the type of parking category. Fig. 10 shows a condition when the user pressed button 1 (low logic) for the women-only selection. As a result, the green LED lights up (LEDG0 = 1) and the buzzer produce a beep sound (buzzer = 0). Parking spot number 7 which is allocated for women is available based on the current value of the irdetect_carpark signal (12'b110001001110). The SEVENSEG1,2,3 is set to "007" for the assigned parking spot and SEVENSEG4 is set to "1" for the push button selection. In the same figure, the condition when the user selects push buttons 2, 3, and 4 was also presented. SEVENSEG1,2,3 change to a new parking spot according to the category of the selected push button.

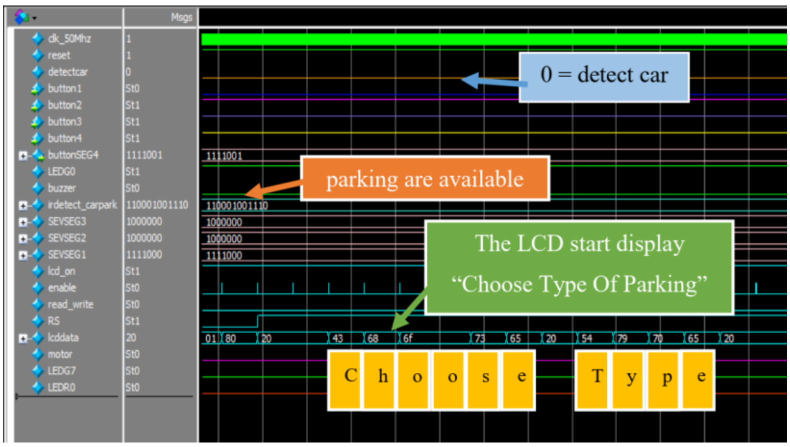


Fig. 9 - The LCD will display 'Choose Type of Parking' when the car is detected and parking spots are available

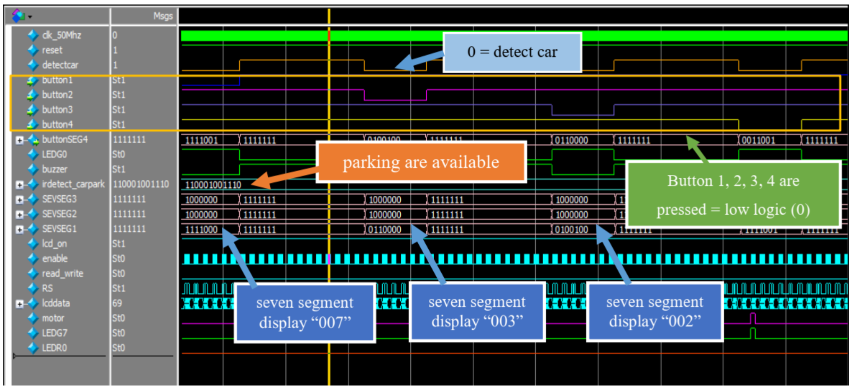


Fig. 10 - When a car is detected and parking spots are available for different women only

Fig. 11 shows the timing diagram for different parking conditions when the parking spots for the selected category are full and normal parking is also full. At this condition, the seven segments for the assigned number of parking spots displayed nothing, however, the seven segments for push-button selection will display the number of selections when the button is pressed. The green LED lights up (LED = 1) and the buzzer emits a beep sound (buzzer = 0) when the button is pressed. Fig. 12 shows that, when the number of assigned parking spots is already displayed on the seven segments, the motor is open (motor = 1) and the green LED lights up. And when the IR sensor at the automatic bar detects no car at the automatic bar, the motor will automatically close (motor = 1) and a red LED light up.

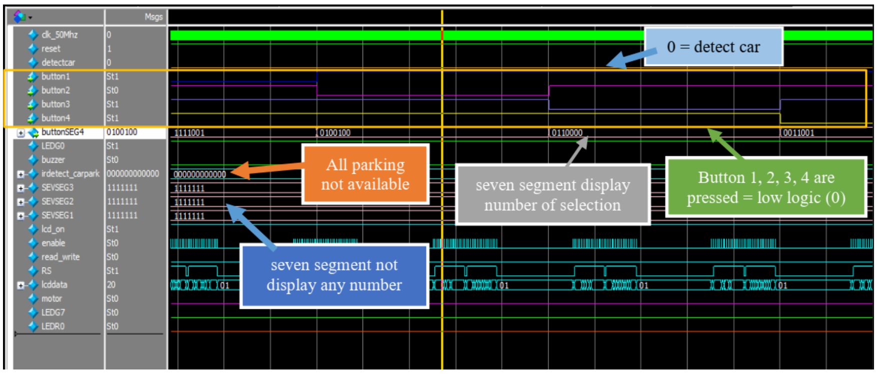


Fig. 11 - When the button is pressed and all of the parking spots are full, the seven segments for assigned parking spot numbers display nothing

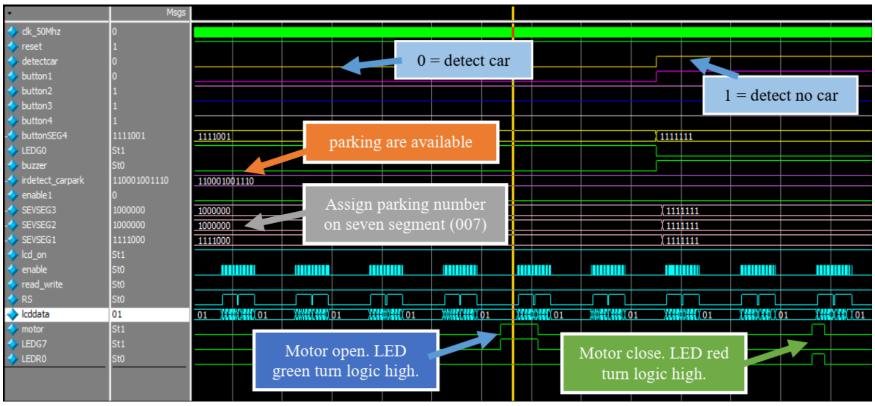


Fig. 12 - The green LED (LEDG7) lights up whenever the motor is turned on. When no car is detected at the automatic bar, the motor automatically closes and the red LED (LEDR0) lights up

3.2 Functional Hardware Verification using FPGA Altera DE2-115 Board

The complete hardware implementation on the FPGA Altera DE2-115 board, which comprises the project's input and output components, is depicted in Fig. 13. The OKU parking spots are monitored by IR sensors 1 and 2, while pregnant women/elderly parking spots are monitored by IR sensors 3, 4, and 5. IR sensors 5, 6, and 7 are used to monitor parking spots for women only, while IR sensors 8, 9, 10, 11, and 12 are used to monitor parking spots for normal parking. Push buttons 1, 2, 3, and 4 are used as the user's input for the user's category. The information/instruction message will be displayed on the LCD, and the first three seven segments will be used to display the assigned parking spot number. The fifth seven segments are used to display the parking types selected by the user. There is also a buzzer and LED, as well as an IR sensor at the automatic bar.

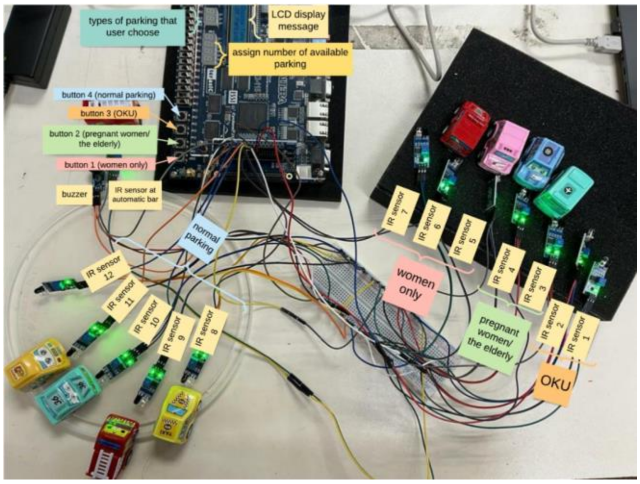


Fig. 13 - The prototype of the hardware implementation on the FPGA Altera DE2-115 for the smart parking spot allocation system

When no car was detected at the automatic bar, the LCD displayed "Welcome To Vixx Mall" as shown in Fig. 14. Fig. 15 depicts the LCD displayed "Choose Type Of Parking" after a car has been identified at an automatic bar and parking spots are available. Fig. 16 depicts an LCD displaying "Sorry No Parking" when a car is spotted at an automated bar and all accessible parking spots are occupied.

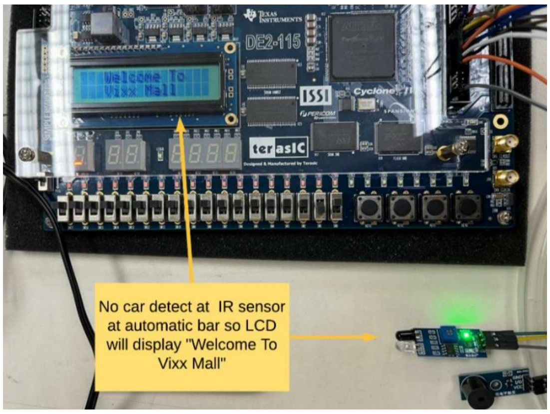


Fig. 14 - When no vehicle was detected at the automatic bar, the LCD displayed "Welcome To Vixx Mall"

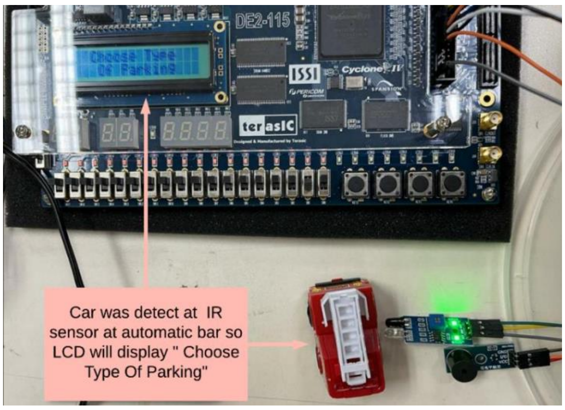


Fig. 15 - When a car was detected at an automatic bar and parking spots were available, the LCD displayed "Choose Type Of Parking."

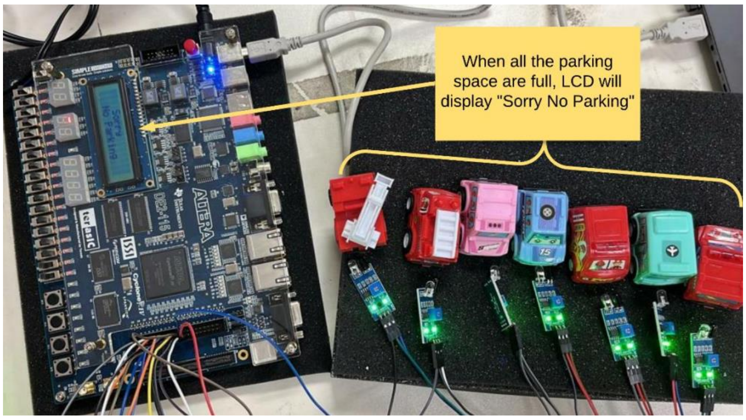


Fig. 16 - When a car was detected at an automatic bar and all parking spots were full, the LCD showed "Sorry No Parking."

The green LED lights up and the buzzer generates a 'beep' sound when the user presses button 1 for the women option, as seen in Fig. 17. The first segment of the seven segments displayed "1" for the types of parking that the user had selected, which was button 1 for the women only option. The system then read the IR sensors to determine which parking spots are reserved for women. Fig. 17 also shows that the parking IR sensor 6 is the only one that is available. The number "006" displayed on the next three seven segments as the assigned parking spot selected from available parking for women detected by IR sensor 6. As demonstrated in Fig. 18, Fig. 19, and Fig. 20, the approach is the same for pregnant women/the elderly, OKU, and regular parking.

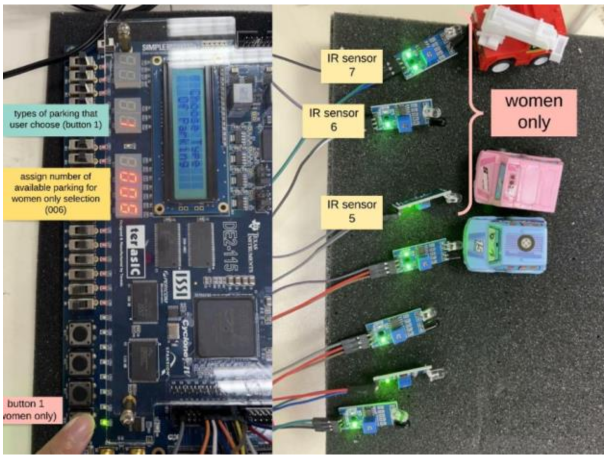


Fig. 17 - When button 1 (women only) was selected, women’s parking is available, women’s parking spot number 6 (location of IR sensor 6) was assigned and seven segments displayed "1 006"

When the pregnant women/elderly button (button 2) is selected, the LED lights up and the buzzer generates a 'beep' sound, which can be seen in Fig. 18. The seven segments displayed number "2" for the type of parking, which was button 2 for pregnant women and the elderly. Then, the next three seven segments displayed "003" as the assigned parking spot because IR sensor 3 which is located at parking spot number 003 for pregnant women/ elderly is available.

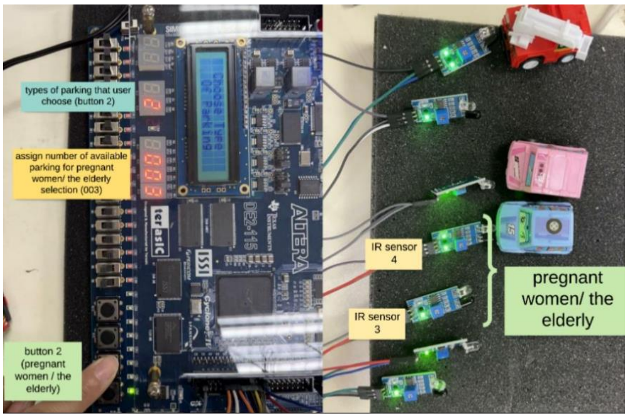
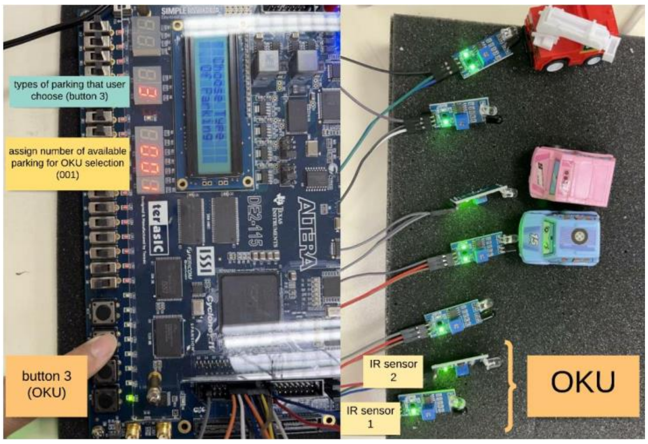
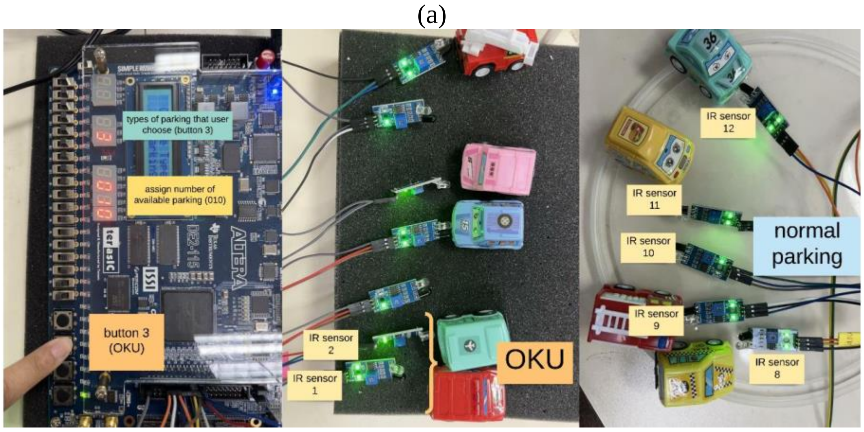


Fig. 18 - When button 2 (pregnant women/elderly) was selected, pregnant women/elderly parking spot is available, pregnant women/elderly parking spot number 3 (location of IR sensor 3) was assigned and seven segments displayed "2 003"



(a)



(b)

Fig. 19 - When button 3 (OKU) was selected (a) OKU parking spot is available, OKU parking spot number 1 (location of IR sensor 1) was assigned, and seven segments displayed "3 001". (b) OKU parking spot is unavailable, normal parking spot number 10 (location of IR sensor 10) was assigned and the seven segments displayed "3 010"

When button 3 for OKU is selected, the seven segments displayed "3" for the types of parking that the user selected, and the green LED illuminated and the buzzer produced a "beep" signal, as seen in Fig. 19(a). The system scanned the IR sensor at the OKU parking area and the next three seven segments displayed "001" as the assigned parking spot because IR Sensor 1 detects no vehicle at parking spot number 001 which is allocated for OKU. While for Fig. 19(b), button 3 is selected, but parking spots for OKU are fully occupied. Therefore, the system automatically assigned a normal parking spot to the user where at this time normal parking spot number 010 is available (detected by IR sensor 10), and thus, seven segments displayed “010” as the assigned parking spot.

When the user select button 4 for normal parking selection, the seven segments displayed "4" for the category of parking, and the green LED and buzzer lit up and emitted a "beep" sound, as shown in Fig. 20. At the normal parking option, the system read the IR sensor, and the seven segments displayed "012" as the assigned parking spot because parking spot number 012 is the only parking spot that available for normal parking.

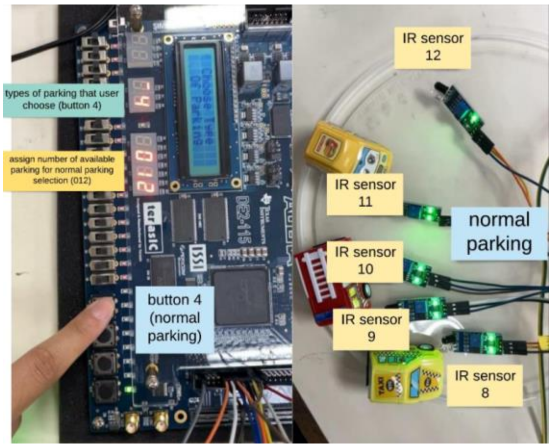


Fig. 20 - When button 4 (normal parking) was selected, the normal parking spot is available, normal parking spot number 12 (location of IR sensor 12) was assigned and the seven segments displayed "4 012"

The prototype has been tested with several parking spot conditions with different types of user categories. Table 3 tabulates the allocation result for 12 tests. For each test, the parking spot assigned by the system is evaluated to determine the correctness of the parking spot category and the accuracy/sensitivity of this parking spot allocation system. Note that, the correct parking spot for each category can only be obtained when there is at least one available parking spot for the selected category, otherwise, a normal parking spot will be assigned to the user. The accuracy of this system is measured based on the system's operation and also represents the system's sensitivity.

Table 3 - Allocation results for 12 tests conducted at different parking spot conditions

No. of Test	User's Category (selected by the user)	Parking Spots Conditions (1-not available, 0-available) Parking spot binary digits for the selected user's category are highlighted in yellow	Parking Spot Assigned to the user	Correct Parking Spot Category? (Y/N)	Accurate Allocation? (Y/N)
1	Women (Button 1)	12'b111111010110	006	Y	Y
2	Women (Button 1)	12'b011110000111	005	Y	Y
3	Women (Button 1)	12'b110001111010	008	N	Y
4	Pregnant/Elderly (Button 2)	12'b110001110111	004	Y	Y
5	Pregnant/Elderly (Button 2)	12'b110111101011	003	Y	Y
6	Pregnant/Elderly (Button 2)	12'b110111001110	010	N	Y
7	OKU (Button 3)	12'b110001001110	001	Y	Y
8	OKU (Button 3)	12'b001111001111	011	N	Y
9	OKU (Button 3)	12'b111100101100	001	Y	Y
10	Normal (Button 4)	12'b010111001110	010	Y	Y
11	Normal (Button 4)	12'b111111001110	-	Y	Y
12	Normal (Button 4)	12'b010001001110	008	Y	Y
	Percentage of correctness/accurateness			Correctness 9/12 = 75%	Accurateness 12/12 = 100%

Based on the allocation results for the 12 conducted tests, 9 out of 12 tests recorded correct parking spot allocation addressing the selected user's category. While the other 3 tests recorded incorrect parking spot allocation due to unavailable parking spots for the selected category. The allocated parking spot was in the normal category parking spot. The correctness of the parking spot category was calculated as 75% which depends on the parking spot availability.

However, the accuracy or sensitivity of the system is recorded as 100% based on the expected output of the system. For the 11th test, the users might get frustrated due to full parking for the normal category because available parking spots were under OKU and women's category only. Normal users are only allowed to park at normal parking spots. To overcome this issue, this parking system should be able to notify the type of parking category that is available at the first parking entrance, so the user does not need to enter the first parking entrance if the parking spots for their category is full. This will be considered for improvement.

The use of FPGA in this system helped a lot in reducing the work on developing the project prototype at a minimum cost. Most of the on-board input-output devices such as LEDs, LCD, seven-segment display and push buttons were suitable for this project, additional input-output devices such as IR sensors, motor, and buzzer were successfully connected to the general-purpose input-output (GPIO) terminal on the FPGA. The reprogrammable feature of FPGA allows for project improvement. Modifications can be made anytime to cater to any issue that needs to be considered. FPGA is suitable for complex system designs such as this parking space allocation system design that will be used for large buildings in real with a very large number of parking spots. The use of a microcontroller or single-board computer is not recommended for the parking spot allocation system because of the limited number of input and output interfaces and the slow speed. The speed of FPGA is greater than microcontrollers because of its parallel processing. Additionally, FPGA also has multiple features such as an ethernet connection, built-in memory, and others. These features might be useful to improve this parking spot allocation system design to include the parking spot monitoring process as well.

4. Conclusion

In conclusion, the controller for the Smart Parking Spot Allocation System for a single-level parking area has been successfully designed using Verilog HDL by using the Quartus Prime Lite Edition tool. The system has been successfully verified using the Questa Intel Starter FPGA Edition tool with the use of a test bench as the input to the system. The timing diagram shows the correct results according to the allocation process based on the user's category and priority. The hardware functional verification is verified by the developed prototype which is implemented using FPGA Altera DE2-115. The hardware recorded 75% correctness based on the correct parking spot according to the category selected by the user and 100% accuracy based on the expected output of the system. This Smart Parking Spot Allocation System project is basically in the prototype phase, and it only works with a small number of components and on a small scale. It is, nevertheless, expandable, and more IR sensors may readily be added to detect a larger number of parking areas. As a result, its scale may be simply altered and updated to provide more features to meet specific requirements such as parking space monitoring as well.

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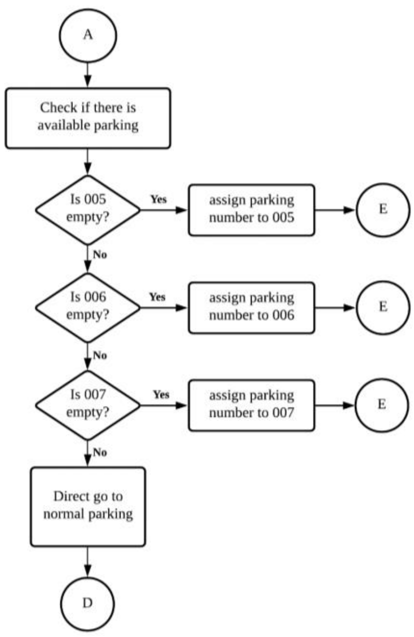
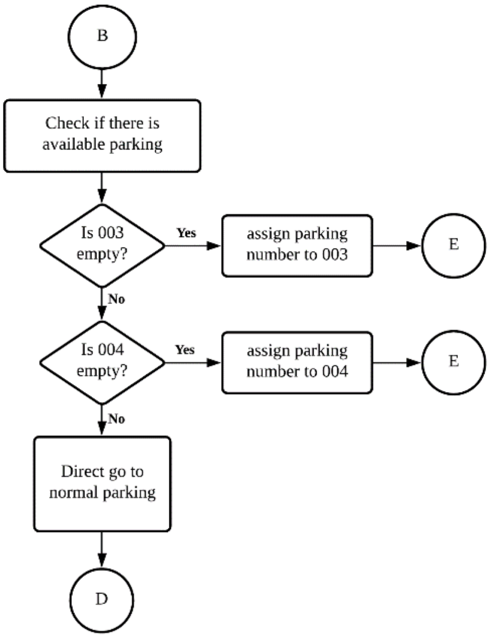
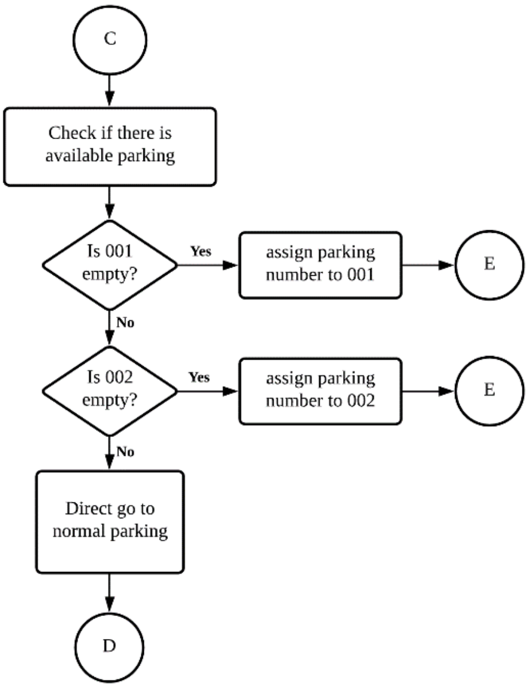
Appendix A: Additional Flowchart



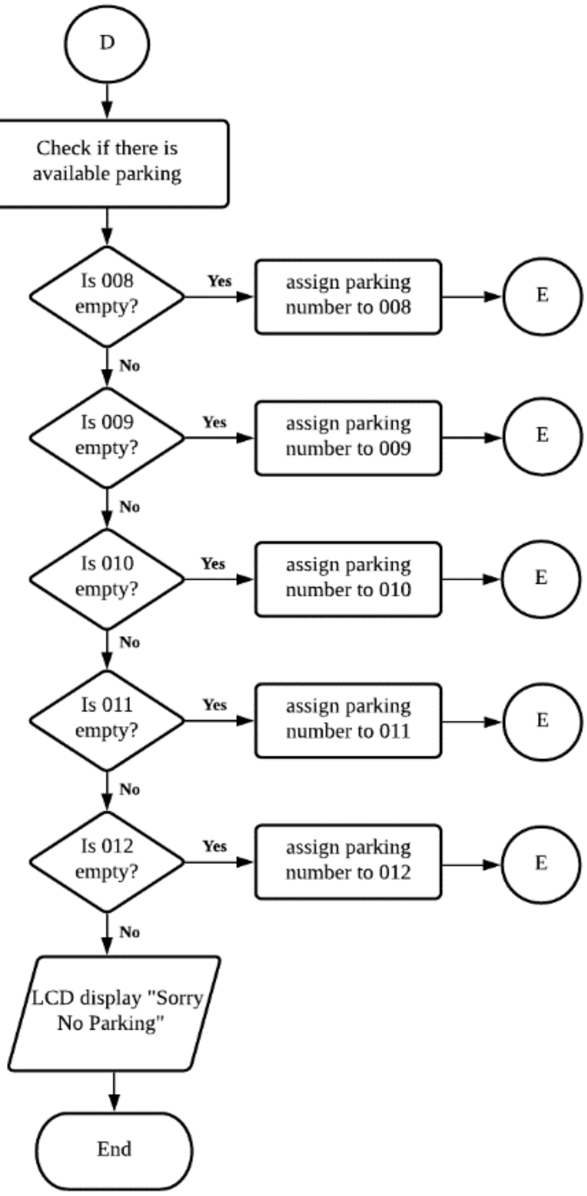
A1: Flowchart selection for women only of the Smart Parking Spot Allocation System's Controller



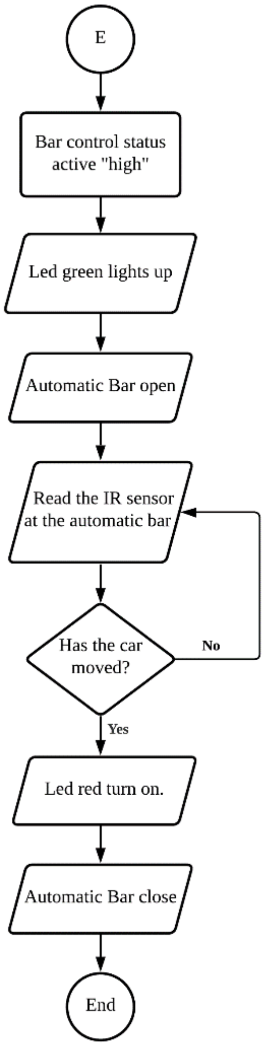
A2: Flowchart selection for pregnant women or the elderly of the Smart Parking Spot Allocation System's Controller



A3: Flowchart selection for persons with disabilities (OKU) of the Smart Parking Spot Allocation System's Controller



A4: Flowchart selection for normal parking of the Smart Parking Spot Allocation System's Controller



A5: Flowchart of the automatic bar control module for the Smart Parking Spot Allocation System's Controller

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