DEVELOPMENT OF A SOLAR-POWERED AUTOMATIC CAR PARK MANAGEMENT SYSTEM

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Abstract: *Parking of cars can be considered a serious issue in developed and developing nations. Many cities suffer from a lack of automobile parking space because of the rapid increase in number of car owners. Urban parking issues often stem from an imbalance where the number of cars seeking parking exceeds the available parking spaces, creating a persistent congestion and difficulty in finding suitable parking spots. The manual system of managing car parking space can be cumbersome and always prone to chaos. Most efforts found in literature to automate car parking systems concentrate on software solutions, either using image processing to find vacant spaces or using mathematical methods to find and reserve a parking space. The aim of this work is to design and implement a solar-powered car park automation system using sensors (light dependent resistor sensors and infrared sensors) and controllers (Arduino). The system is designed to improve the efficiency and convenience of car park operations, while also reducing energy consumption and the carbon footprint of the car park. To achieve this, the sensors and controllers that automated the car park's operations were powered by solar panels installed in the car park. Sensors were used to detect the presence of vehicles in the car park and to determine the availability of parking spaces, while controllers were programmed to open and close gates, control lighting and ventilation. The solar-powered car park automation system was tested and evaluated under different conditions and at different times of the day to show that the system was able to reduce energy consumption and improve the utilization of parking spaces in a closed area. The system was found to be 99.5% reliable with no false positive but single false negative attributed to accidental error. The system is easy to use and assist towards achieving sustainable development goals 7, 9, 11 and 13.*

1. INTRODUCTION

In both developed and developing nations, there are serious issues with parking in metropolitan areas [1]. Many cities suffer from a lack of automobile parking spots as a result of the fast increase in car ownership, with an imbalance between parking availability and demand, which may be seen as the root cause of urban parking difficulties. This work is motivated by the challenges that automobile owners have while trying to find a parking spot because of the increase in the number of vehicles on the road. According to a global parking survey by IBM, in some situations, such as urban regions, it takes the vehicle an average of 20 minutes to find a parking space [1]. According to statistics, the process of searching for an empty parking lot causes 30 per cent of traffic congestion on average [2]. As a result, drivers waste a lot of time looking for available parking spaces and use more gasoline for that search. For instance, research conducted in France in 2006 revealed that the yearly loss associated with seeking of parking space is 700 million Euros [3]. In recent research, the time lost due to congestion in Washington was calculated to be 1433 dollars annually per vehicle commuter

[4]. Every year, automobiles looking for parks in some areas, including the commercial district in Los Angeles, use 47,000 gallons of gasoline and create 38 journeys around the world are equivalent to 730 tons of carbon [5]. When the reasons for parking issues were examined, it was discovered that there are two main issues at play. The first is due to unstructured parking; whereby motorists fail to precisely park between lines which lead to incorrect parking, when some vehicles park on two parking spots simultaneously, or due to the inexperience of the driver or any other reason. The term "inefficient use of current park capacity" [6] and "parking lot usage" [7] are used to describe this issue. The other problem is entering the parking lot when there are no available spaces, which causes congestion as parking searchers build up. Researchers used a variety of techniques to automate and optimize parking lots use. The approach that is most frequently used is image processing of the automobile parking area [8]. In some other cases, trained neural networks predict the occupancy conditions of the parking lot based on the visual features collected from parking spaces [7]. A car park automation system is a system that uses technology to control the entry and exit of vehicles in a parking lot. It typically consists of sensors and controllers. One of the main components of a car park automation system is the sensor, which is used to detect the presence of vehicles. Sensors can be classified into two types: passive and active. Passive sensors, such as inductive loop detectors, use a coil of wire buried in the ground to detect the presence of a vehicle. Active sensors, such as Radio Detection and Ranging (RADAR) or Light Detection and Ranging (LIDAR), use electromagnetic radiation to detect the presence of a vehicle. The controller is the central processing unit of the car park automation system. It receives input from the sensors and processes this information to determine the appropriate action to take. For example, if a vehicle is detected entering the car park, the controller may open the gate or raise a barrier to allow the vehicle to enter. Solar panels are also used in car park automation systems to provide a source of renewable energy. Solar panels can be used to power the sensors, controllers, and other electronic components of the system. There have been several studies on the use of car park automation systems, including the use of solar panels, sensors, and controllers. One study examined the feasibility of solar parking lots for electric vehicles [9]. The study found that the use of solar panels resulted in a significant reduction in energy consumption and a corresponding reduction in carbon emissions. Overall, the use of car park automation systems involving solar panels, sensors, and controllers has been shown to have several benefits, including reduced energy consumption, improved efficiency, and reduced congestion. The drive behind creating a solar-powered smart car park management system is closely linked to advancing Sustainable Development Goals (SDGs) 7, 9, 11 and 13. These goals promote the significance of clean energy, innovation, infrastructure development, climate action and the creation of sustainable urban areas [10]. To this end, implementing such system will actively contribute to the utilization of clean energy sources, foster technological innovation in infrastructure management, and enhance the sustainability of cities and communities. In contrast to previous work, here we propose a prototype of a simple and cost-effective design of solar-powered automatic car park management system suitable predominantly for indoor parking space. The rest of the manuscript is organized as follows. Section 2 reviews some related work, section 3 describes the methodology, section 4 presents and discusses the results while section 5 is the conclusion.

2. RELATED WORK

An RFID-based automatic parking system was suggested by Hanche et al [11]. Since each motorist will have an RFID card that will be utilized to process the payment of parking costs without stopping at the circulation point, their system will enable quick entry and exit. By using this technique, the parking space's entrance and departure are less congested. Based on Chinrungrueng et al. [12], an optical wireless sensor network (WSN) for traffic monitoring was created, and it may be used to keep an eye on the cars parked nearby. The device may alert cars to parking places that are available and then point them in that direction. It would be quite simple for vehicles to locate a vacant space in a congested parking garage with this sort of technology. A smart parking system prototype was created by Yang et al [13] and consists of a collection of light wireless sensor networks installed for each parking space and connected to an integrated web server to show the position of the empty slot on a Google map in real time. However, as in-building parking spaces cannot be displayed on the Google map, this approach is not relevant for such spaces. A surveillance system that can spot persons who damage other cars or obstruct other cars due to improper parking is necessary in addition to being able to locate an empty parking space in a parking area. The car may have been struck, dented, scratched, or scraped. Aalsalem et al [14] presented a parking management system that keeps an eye on the parking lot using Automatic Number Plate Recognition (ANPR) cameras connected via LAN to a database that has data on the owner of each vehicle identified by its license plate. This technique can be used in parking lots that are frequented by certain types of drivers, such as those at universities. The authors suggested computer vision in the references [15] and [16], by combining the parking space with CCTV and camera nodes built on a visual sensor network. Here, the photos are compressed before being delivered along with the data to the controller, which requires a lot of storage space and pricy camera use. The breadth of identification is limited by the object's detection accuracy level. The IoT layers, sensor technologies for slot identification, and how to connect them to the central server were all covered by the authors in [17] and [18]. According to the IoT-based levels, the papers were divided into a three-layer method (sensor, communication, and application layer). They insisted on installing a sensor and wiring connections at each slot to link each sensor to their regional servers. This may make it more expensive and take longer to transmit data from each sensor to its local servers than from local servers to a central server. Above all, they spelt out gateway transactions in an easy-to-understand manner. Williams [19] proposed a wireless sensor-based car parking system where each slot is monitored by some set of sensors and the sensors send the signals to the microcontrollers. There is also an LCD display at the entrance of the park to inform drivers if there is no parking slot available. There has been a growing interest in the use of solar power as an alternative energy source in car park automation systems. Solar panels can be installed on the roof of a car park to generate electricity, which can be used to power the sensors and controllers that automate the car park's operations. One advantage of using solar power is that it is a clean and renewable energy source that can reduce the carbon footprint of the car park. The author in [20] introduced a prototype for a solar-powered smart parking system. However, the primary emphasis was placed on aspects such as the sizing of the photovoltaic (PV) system and the implementation of an obstacle detection system for vehicles, rather than focusing on the management of parking spaces. It can be shown from the literature that researchers created several methods to address the issue of parking use. They mostly concentrate on software solutions, either using image processing to find vacant spaces or using mathematical methods to find and reserve a parking space. This work develops a simple prototype of automatic solar-powered car parking system that can be used for example in an indoor parking system and considers optimal selection of appropriate hardware and software components.

3. METHODOLOGY

The design implementation is broken down into 3 major sections as shown in Figure 1, namely the power, logic, and control sections.

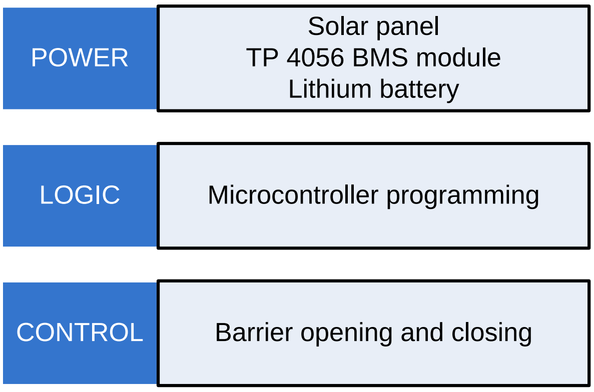

Fig. 1 Sections of the design

3.1. Power section

The power section consists of a TP4056 BMS module, two 3.7 V lithium batteries and 6 V solar panel. The TP4056 BMS module is a battery management system (BMS) module used to charge the batteries and ensure there is no overcharging of the batteries to prevent them from getting damaged. It provides a USB charging port for charging the batteries with an external charger and a port to accommodate the solar panel. The components in the car parking system require around 5 V for their operation. The two 3.7 V lithium batteries are connected in series and are used to supply the whole car park management system. Lithium batteries were chosen because of their small size, fast charging, and high depth of discharge compared to lead acid batteries. The power audit of the system is first determined to obtain the required solar power for the system. This is shown in Table 1.

Table 1 Estimated power consumption of component used

Components	*Current (mA)*	*Voltage (V)*	*Power (W)*
Microcontroller and sensors	*55*	*5*	*0.275*
DC Motor	*270*	*5*	*1.35*
LCD	*40*	*5*	*0.2*

Thus, the estimated minimum power to be consumed by the components is 1.825W.
For a 24 hrs system, the total energy is given by:

$$1.825\text{ W x }24\text{ hrs} = 0.0438\text{ kWh} \quad \text{(i)}$$

Watt peak is the Energy (kWh) per peak hours of sunlight given as:

$$\text{Watt peak} = \frac{\text{Total energy required (Watt−hour)}}{\text{Peak sun hour}} = 0.0438\text{ kWh x}\frac{1000}{5}\text{hours} = 8.76\text{ Wp} \quad \text{(ii)}$$

The peak sun hour within the locations around Lagos is taken to be 5 hours based on the average duration when the sun intensity would be 1000 Watt/sq-meter.
The number of panels required is:

$$N = \frac{\text{Watt peak}}{\text{Rating of a single panel}} \quad \text{(iii)}$$

Using a standard solar panel of rating 6 V 10 W, the number of panels required given as:
$N = \frac{8.76}{10} \approx 1$, which is approximately a single 6 V, 10 W panel.
For a 5V Lithium-ion battery with a depth of discharge of 95 %, the battery capacity is given by:

$$Battery\ Capacity\ (Ah) = \frac{\text{Adjusted Energy Requirements (Watt − hour)}}{\text{Depth of Discharge} \times \text{Battery Voltage}} = \frac{43.8}{0.95 \times 5} = 9.22\ Ah \quad \text{(iv)}$$

The cable sizing depends on several factors such as the distance between the solar panels, the current carrying capacity of the cable, and voltage drop considerations. As a rule of thumb, up to 5 meters length, the cable size can be taken as [21]:

$$Square\ mm = \frac{Maximum\ current}{3} \quad \text{(v)}$$

To determine the charge controller rating, we use:

$$Solar\ Panel\ Array\ Current\ (A) = \frac{\text{Total Power Output (W)}}{\text{System Voltage (V)}} \quad \text{(vi)}$$

$$Solar\ Panel\ Array\ Current\ (A) = \frac{1.825\text{ (W)}}{5\text{ (V)}} = 0.365\ A$$

The adjusted solar panel array current can be obtained by including a safety margin of around 25 %, thus:

$$Adjusted\ Solar\ Panel\ Array\ Current\ (A) = 0.365 + 0.25 \times 0.365 = 0.456\text{ A}$$

The estimated component specification is summarized in Table 2.

Table 2 Sizing of the solar power

Components	*Rating*
PV Sizing	*8.76 Wp*
Battery	*9.22 Ah*
Charge Controller	*0.456 A*

3.2. Logic section

The logic section involves the programming of the microcontroller (Arduino uno module) and interfacing it with the sensors. The proximity sensors identify when a vehicle is approaching and send a signal to the microcontroller. The microcontroller checks with the LDR sensors to see if there is an available slot and communicates with the servo motor to open the gate/barrier. If there is no available slot, the gate remains closed.

3.3. Control section

The control section actuates the opening and closing of the barriers and turning of the night light on and off. The proximity sensor detects the presence of cars in front of the gate. The servo motor controls the barriers while a light dependent resistor (LDR) is used to sense the presence or absence of cars in each parking slot. When the car park has an empty slot, the barriers will open for approaching vehicles and when all the parking slots are occupied the barriers remain closed. For vehicles leaving the park, the barriers will be opened. In addition, the night light can also be triggered to turn on under dark environment, such as at night or when it's about to rain and the weather is not bright. The flow chart of system operation is shown in Figure 2.

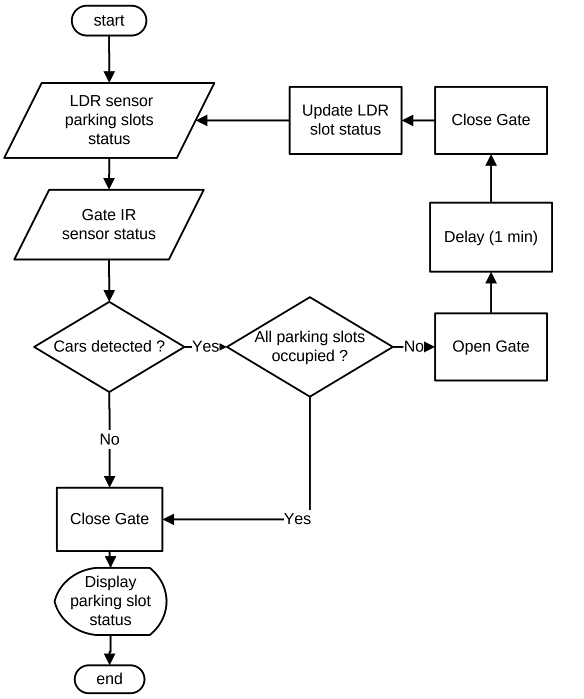

Fig. 2 Flowchart of the automatic car park management system

It should be noted that the proximity sensor is positioned close to the gate; therefore, the barrier will remain open as long as a car is detected within the range of the proximity sensor. Additionally, the system is designed with the assumption that the car is driven into the parking lot after a set delay time.

3.4. Circuit Diagram

The wiring diagram for the entire system is illustrated in Figure 3.

In the absence of a parked vehicle, the Light Dependent Resistor (LDR) exhibits low resistance, approximately 100 Ω, causing the analog PINs A0 - A4 to register a positive voltage. Conversely, when a car occupies a parking space, the LDR becomes shaded, causing its resistance to surge to as high as 100 M Ω. Consequently, the analog PINs A0 - A4 are driven toward a near-zero voltage level. In addition, an infrared proximity sensor is used to identify approaching vehicles at a minimum distance of approximately 10 cm from the barrier. The barrier is activated by a small dc motor powered by 5 V supply from the microcontroller.

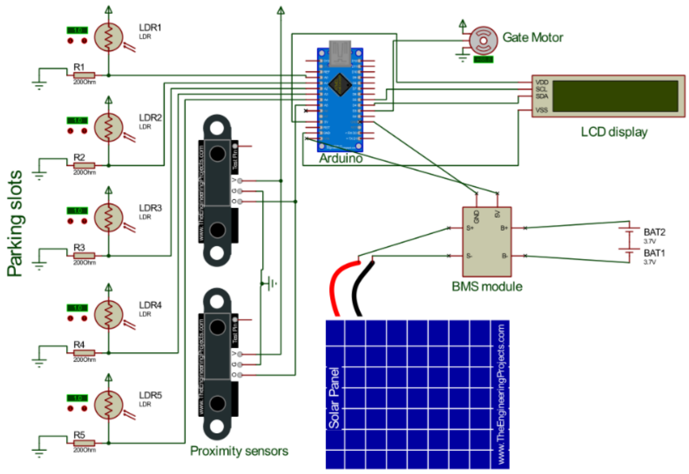

Fig. 3 Wiring diagram of the developed solar-powered car park management system

4. RESULTS AND DISCUSSION

The prototype of the designed system is shown in Figure 4 and 5. The whole system is powered by battery charged with solar power unit and consisting of barrier controlled by proximity sensor and dc servo motor, parking lots units sensed with light dependent resistor, microcontroller (Arduino Uno) and liquid crystal display. The prototype was tested using the following metrics:

1. Confusion matrix
2. Reliability test
3. Latency test
4. Power requirements

Fig. 4 Design Prototype of the automatic car park management system

Fig. 5 Microcontroller system with LCD

4.1. Confusion matrix

The prototype was randomly tested to determine whether it responded appropriately using a confusion matrix. A confusion matrix is a frequently used tool in data analysis and machine learning to assess the effectiveness of categorization models.

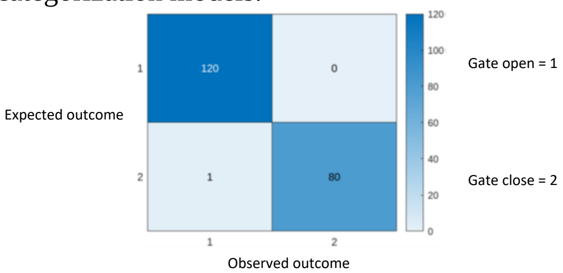

Fig. 6 Confusion matrix heatmap for the evaluation of the system

It offers a succinct description of a classification problem's anticipated and actual classes, enabling the evaluation of model precision, recall, and other crucial metrics. This methodology was used to evaluate the performance of the developed prototype and there are two classes corresponding to the observed and expected outcomes during the test. There are four possible scenarios as shown in Figure 6 which are 11, 12, 21, and 22. The case 11 (true positive) is when there is a positive match between the observed and expected outcomes. This is for instance a scenario when the barrier was opened because the proximity sensor senses a car in front of the barrier alongside an available car park slot. In the instance of true negative (case 22), there is a negative match between the observed and expected outcome. This can for example be a case where the barrier remains closed as expected because there are no available car park slots, irrespective of the presence or absence of cars in front of the proximity sensor at the gate entrance, or the barrier was closed when there are available parking slots but no cars at the entrance of the gate. The case 12 are false positives which refers to a scenario where the barrier was opened when there were no car parking slots or barrier opened when there were available parking slots but no cars at the entrance of the gate. The condition 21 are false negatives which is a scenario where the barrier is always closed while there is an available parking space alongside presence of a car in front of the gate. The prototype was manually tested for 200 times with a random selection of 120 true positives and 80 true negatives and a confusion matrix was obtained as shown in Figure 6. Result shows that there no false positives, but there is a single false negative which can be attributed to error due to the gate proximity sensor.

4.2. Reliability

The system reliability (R) of the developed system was determined from the relation:

$$R = \frac{Success}{Trials} \qquad \text{(vii)}$$

In this case, success is defined as the sum of true positives and true negatives. Therefore, a system reliability of 99.5% was obtained after 201 trials.

Based on the results obtained from the confusion matrix and reliability test, it can be concluded that the design is reliable as the prototype behaved exactly as intended. However, LDR sensors cannot distinguish between a vehicle and any other object so there might be errors if a slot is covered by an object or even human. To combat this, intelligent systems can be designed to distinguish between a vehicle and another obstruction that might cause the sensor to identify a slot as occupied. Therefore, this design is mostly suitable for closed parking lots, such as in the malls or airports where only cars have access to the car park.

4.3. Latency test

Testing for latency is done to determine how quickly a system or network responds to a prompt or request. Here, the response time after detection of cars, program response and of opening of barrier was measured and average latency time obtained was 3.5 s.

4.4. Power requirements

The solar panel provides a 6 V to the system. This power is stored in two 3.7 V lithium-ion batteries. The Battery Management System (BMS) module then regulates this stored power, converting it to a steady 5V supply required by the Arduino system.

5. CONCLUSION AND RECOMMENDATION

The solar-powered car parking automation system represents a remarkable forward leap in efficient and sustainable parking management. This innovative approach harnesses sensor technology and renewable energy to expedite parking processes, enhance consumer convenience, and champion environmental sustainability. By seamlessly incorporating solar energy into the automated parking system, we substantially reduce reliance on conventional power sources and minimize the carbon footprint associated with parking facilities. The system perpetually draws from the sun's clean, renewable energy via its solar panels, ensuring uninterrupted functionality, while simultaneously curbing operational expenses and reducing dependency on the electrical grid. The developed prototype demonstrated 99.5 percent reliability rate, minimal false positives and negatives, user friendly operation, and a high degree of user satisfaction. The developed system is particularly well-suited for enclosed parking facilities, such as those found in shopping malls and airports, where access to the parking area is restricted to vehicles only.

To ensure practical implementation of the system in real-life scenarios, several enhancements are necessary. These include optimizing the barrier mechanism by integrating heavy-duty industrial servo motors capable of efficiently driving the barrier. Additionally, employing a proximity sensor array with precise calibration to detect vehicles extending beneath the barrier is essential. Installing a large Liquid Crystal Display (LCD) screen at the park entrance to provide real-time status updates is also imperative. Adequate consideration should be given to selecting a suitable power supply to ensure efficient operation. For systems incorporating a high number of sensor nodes, (exceeding 100), adopting wireless communication between sensor nodes and the central microcontroller is crucial. Utilizing steel-plated frames to secure externally installed electronic components and circuits enhances overall system durability. Moreover, careful calibration of sensors and addressing other pertinent factors are crucial for optimal system performance and reliability over the long term. By implementing these measures, the system's deployment can be made more effective and reliable in practical environments.s

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