Development of Smart Parking Detection System with IoT Technology

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Abstract. An increasing number of people are driving more cars and cities, which has increased the need for effective parking options. This project creates a reliable, real-time smart parking system for open parking arrangements. This research involves designing an IoT smart parking system utilizing the most suitable sensors. Then, it will implement the robust data analytics techniques to efficiently process data from sensor and provide reliable real-time updates on parking spot status. Through this comprehensive approach, the goal is to enhance the accuracy and efficiency of parking management in open spaces. The methodology includes determining the system's requirements and creating the sophisticated architecture with the necessary hardware, software, and networking protocols in place to guarantee optimal performance. The following stage is determining an appropriate sensor to be used in open parking area. Extensive trials are carried out to evaluate their efficiency and dependability in precisely identifying the presence of vehicles. After that, the system is put into a controlled setting and an open parking lot in the real world. It is then thoroughly tested to determine its accuracy, dependability, and performance under various conditions. This smart parking system not only improves the efficiency of parking management but also contributes to reducing traffic congestion in UiTM parking spaces inside Shah Alam campus.

Keywords: Smart Parking System, Sensor data, Vehicle detection, IoT Technology.

1 Introduction

As urbanization intensifies, the demand for efficient parking solutions has grown due to increased vehicle usage, causing traffic congestion. Traditional parking management systems often fail to provide real-time information, leading to inefficiencies and frustration for drivers searching for available parking spots [1]. Studies indicate that 30 per cent of the traffic, on average, is spent by drivers cruising for parking, and the average time a vehicle takes to find a space at the curb ranges between 3.5 and 14 minutes [2]. The increment in traffic congestion due to drivers searching for a free parking spot on campus has a huge impact on the quality of life of the students and the staff members (e.g., frustration due to the waste of time, accidents [3]-[6]) and, most importantly, on the environment [7]-[9], in terms of fuel consumption and air quality [10,11]. For instance, it has been estimated that there were as many as 8.9 million excess deaths a year

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due to outdoor air pollution, partially connected to the toxicity of vehicle exhaust. Particularly in open parking arrangements, such as those found on university campuses or public areas, the lack of reserved spots adds complexity to parking management.

Therefore, the project aims to develop a reliable and real-time smart parking system specifically designed for open parking layouts. This system leverages advanced technologies including ESP32 microcontrollers, NE555 timer-based metal detector circuits boosted by operational amplifiers, GPS modules for location tracking, and IoT protocols [12]. Additionally, it incorporates solar panels, charger modules, and onboard batteries to ensure continuous, self-sustaining operation. The primary objective of this study is to explore and evaluate the effectiveness of these sensor technologies in accurately detecting parking spot availability in dynamic environments, particularly at UiTM Shah Alam due to the peculiar challenges faced by university campuses. University campuses often have peak traffic during certain hours of the day [13] that is during the beginning and end of classes. Therefore, acute congestion problems are likely to happen during these periods. By addressing parking management in this study, it hopes to improve daily experiences for students and staff, reduce operational costs associated with parking management, and help towards the sustainability goals of the university.

By integrating NE555 timer-based metal detectors enhanced by op-amp comparators and GPS-based location tracking, the system aims to provide precise, real-time updates on parking spot availability. This integration addresses challenges such as weather resilience and signal interference. The IoT connectivity of the system facilitates remote monitoring, data collection, and real-time updates via various platforms, including mobile applications and connected devices [12]. This connectivity greatly improves user convenience and aids in better traffic management by allowing drivers to efficiently discover and navigate to available parking spots. Through extensive trials and real-world deployment, the system is evaluated for accuracy, reliability, and performance under various conditions. The data collected provides valuable insights for optimizing user experience and overall system efficiency. Ultimately, this smart parking system not only aims to improve the efficiency of parking management but also contributes to reducing traffic congestion and emissions in urban areas [14].

2 Methodology

This study outlines the process of initializing and operating a system composed of an ESP32 microcontroller, a GPS module, a SIM900A module, a solar power module, and a sensing circuit. The system begins with the initialization of the ESP32 microcontroller, which serves as the central unit coordinating all the modules. Concurrently, the solar module is initialized to ensure a reliable power source for the parking system. Meanwhile, the sensing circuit is responsible for detecting cars and the SIM900A module is used for GSM communication and established the network connection to a telco provider. The GPS module is prepared to provide the parking location data. Concurrently, the sensing circuit modifies its frequency to achieve optimal performance subject to the presence of a car. For remote monitoring and control, the ESP32 transmits data, including GPS location and automobile detection, to the Blynk platform after all modules have been correctly initialized and the required data has been collected.

2.1 Equipment and Apparatus

Table 1 lists the items and corresponding apparatus required for the project. Each component has a specific function that is critical for the successful operation of the system. The ESP32 serves as the main microcontroller, providing processing power and connectivity. The Neo Ublox GPS module with Athena ensures accurate location tracking. The SIM 900A module facilitates communication via GSM. The sensing coil is used to detect magnetic fields from the vehicles. The CN3791 MPPT solar charger module optimizes the charging efficiency of the solar panel, which provides a 6V 1W power source. The Li-ion battery with a capacity of 3.7V and 12000mAh (Rakiten) stores energy for the system. The NE555 timer is utilized for time precision applications, and the operational amplifier is used to amplify voltage signals.

Table 1. Equipment used in the system and its functionality

No	Item	Function
1	ESP32	System microcontroller
2	NEO 6M U-blox GPS module with antenna	To provide GPS data for parking
3	SIM 900A module	Network connection to telco service provider
4	CNT3791 MPPT solar charger module	To supply the power source to the system from solar energy
5	Solar panel 6Volt 1Watt	Solar panel
6	Li-on battery 3.7V, 12000mAh	Power energy storage
7	Sensing circuit	To obtain data from the sensor, filter and amplify signal
8	Sensing coil	To detect vehicle

This project as depicted in Figure 1 presents a solar-powered smart parking system designed for efficient vehicle detection and monitoring, leveraging the ESP32-WROOM-32E microcontroller as the central processing unit. A GPS module is used for capturing accurate geographical location data, essential for positioning and tracking the available parking location, and a GSM module facilitates cellular connectivity for remote data transmission, ensuring real-time monitoring and updates. A sensing circuit is employed for vehicle detection, providing reliable data to users. This will make the system a comprehensive solution for modern vehicle monitoring. A custom-designed printed circuit board (PCB) integrates all components, ensuring efficient connectivity and signal processing. The system is powered by solar panels that convert sunlight into electrical power, providing a sustainable energy source and reducing dependency on external power sources. A battery pack stores energy generated by the solar panels, ensuring continuous operation during periods without sunlight. The ESP32 microcontroller orchestrates the entire system, managing data processing and communication

[15]. By integrating GPS and GSM modules, the system enhances its functionality with precise parking locations and robust communication capabilities. By leveraging renewable energy and advanced IoT technologies, this solar-powered vehicle detection and monitoring system offers a self-sustaining, reliable, and efficient solution for various parking spaces in UiTM campuses.

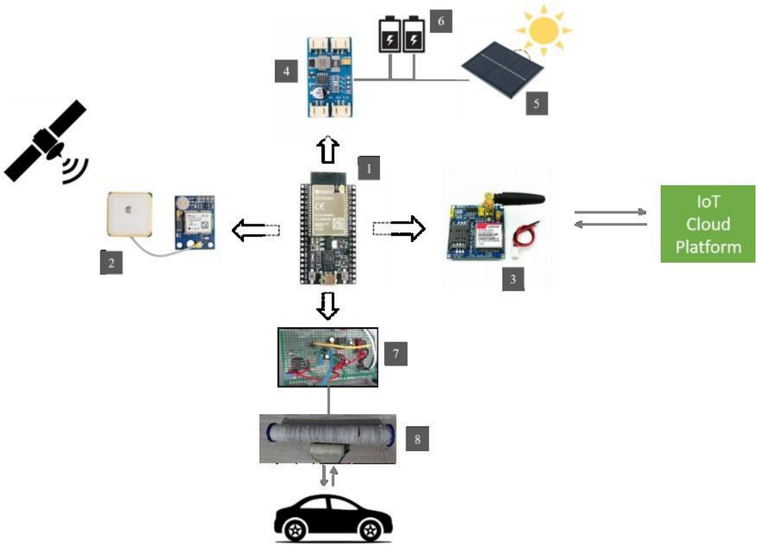

Fig. 1. Overview of the smart parking system equipment with specific number as in Table 1

Vehicle sensing circuit

The NE555 timer IC is employed in the sensing circuit to detect the presence of vehicles based on changes in inductance caused by metal components [16]. When a vehicle enters a parking spot, it alters the inductance of a coil or sensor placed beneath the parking surface. This change in inductance affects the oscillation frequency of the NE555 timer circuit. By setting the NE555 timer to oscillate within a specific frequency range typically 5 kHz to 30 kHz, the system can detect these frequency changes reliably [17]. This frequency range is chosen because it allows for sensitive detection of vehicles while minimizing interference from environmental factors such as electromagnetic noise.

Operational amplifiers are widely used in analogue circuits for signal processing, amplification, filtering, and other functions. In your smart parking system, op-amps play a crucial role in enhancing the detection accuracy and reliability of the NE555 timer circuit. Environmental noise, such as electromagnetic interference and electrical noise, can affect the accuracy of vehicle detection [18]. Op-amps are employed to amplify the small voltage changes induced by the NE555 timer circuit due to vehicle presence. This amplification helps to overcome noise and improve the signal-to-noise ratio, ensuring that the system accurately detects vehicles even in challenging conditions.

Op-amps are also used for frequency comparison in your smart parking system. It compares the output frequency of the NE555 timer circuit which varies in response to vehicle presence with a reference frequency or threshold. This comparison allows the system to determine whether a parking spot is occupied or vacant based on the detected frequency shifts.

NEO-6M GPS Module for Location Tracking
NEO-6M GPS module is integrated into the smart parking system to provide accurate real-time parking location data. This module communicates with satellites to determine the precise geographic coordinates (latitude, longitude, and altitude) of each parking space [19].

NEO-6M GPS module operates on the Global Navigation Satellite System (GNSS), which includes GPS (Global Positioning System), GLONASS (Global Navigation Satellite System), and BeiDou (Chinese navigation satellite system). It receives signals from multiple satellites simultaneously to calculate its position with high accuracy. The module is connected to the microcontroller ESP32 within each parking space unit. The microcontroller processes the GPS data and integrates it with the vehicle detection information obtained from the NE555 timer circuit and op-amps.

3 Results and Discussions

The developed smart parking detection system is tested thoroughly concerning its performance and accuracy in real-time data from the selected sensor and designed sensing circuit. This system is able to integrate the sensing circuit with the NE555 timer along with microcontrollers and GPS module. Besides that, this system is also powered up using solar panels, concerning the operation of outdoor parking areas and clean energy.

3.1 GSM SIM 900A

Since the 3G network is no longer available, this project uses a 2G GSM module instead of a 4G network because it is cost effective. Moreover, with the network speed and its bandwidth, 2G network usage is sufficient for data transfer in this project. Unfortunately, the connectivity to the telco's GSM network is unsuccessful with the SIM900A GSM module. When the SIM card is powered on, it starts an encrypted data exchange process to authenticate itself and confirm its subscription details with the telco's network but due to the weak signal, the connection is unsuccessfully established as depicted in Figure 2 (b). Therefore, a small screen is temporarily used as a user interface to display the system information as in Figure 3 instead of sending the data to a cloud server via this module as the initial design. Even though this module cannot be connected to the 2G network for telemetry system, the functionality is ready for future usage specifically for 4G network connection.

Fig. 2. GSM setup, a) GSM module connecting to a telco service provider, and b) failed connection of the module to 2G network

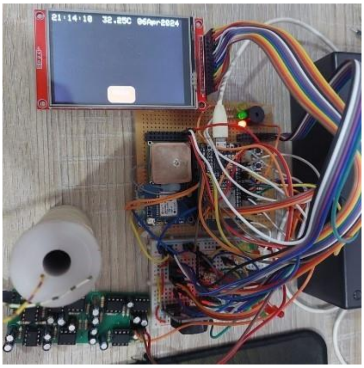

Fig. 3. The system connected to the small monitor as user interface

3.2 NEO 6M U-blox Global Positioning System

This module provides reliable data for tracking and managing parking spot availability for the smart parking system. This robust integration of GPS data enabled real-time updates on parking spot availability, significantly enhancing the management and user experience of urban parking systems. This module is configured to obtain the necessary parking slot data and the user can access the GPS information for the parking as in Figure 4.

Fig. 4. GPS information on the screen

3.3 CN3791 MPPT Solar Charger Module

This solar charger module effectively manages two 6V 1W solar panels connected in parallel, designed for a 9 V input. This setup optimizes energy extraction using MPPT (Maximum Power Point Tracking) technology, dynamically adjusting the operating point of the solar panels to maximize power generation under varying sunlight conditions. The module efficiently charges two 18650 Li-ion batteries connected in series, providing a total capacity of 12000 mAh (3.7 V nominal voltage per cell). During testing, the CN3791 module reliably controlled charging parameters, optimizing voltage and current to maximize efficiency while protecting the batteries from overcharging and deep discharge. The CN3791 MPPT solar charger module features distinct LED indicators that illuminate under specific conditions. A red LED indicates active solar input, showing that the module is tracking the Maximum Power Point (MPP) of the solar panels. Once sufficient solar power is detected, a blue LED indicates that the batteries are charging. This dual LED system provides real-time visual feedback on solar power intake and battery status, crucial for monitoring the module's operation in dynamic outdoor environments where sunlight availability fluctuates. Integrated protections within the CN3791 module, including reverse polarity, overcurrent, and overvoltage safeguards, enhance system reliability and longevity. These features make the CN3791 MPPT solar charger module suitable for a variety of applications such as remote monitoring, IoT deployments, and other scenarios requiring robust and autonomous energy management solutions. Figure 5 shows the information on the solar module where Figure 5(a) and Figure 5(b) present the voltage from the solar panel and load voltage of the system, respectively. Currently, it shows that the load voltage of the parking system is about 5 V.

(a) (b)

Fig. 5. Information for the solar module, a) solar power information, and b) smart parking system's power consumption

3.4 Sensing coil and sensing circuit

Frequency Shift Analysis.

The NE555 timer operating in the sensing circuit plays a crucial role in the vehicle detection system of the smart parking setup. Figure 6 demonstrates a stable oscillation within a targeted frequency range of 5 kHz to 30 kHz. This frequency range is meticulously selected to effectively detect the presence of vehicles based on changes in inductance within parking spots. Through systematic adjustments resistor and capacitor of the circuit, the oscillation frequency is finely tuned to optimize sensitivity and reliability across diverse environmental conditions. During testing, the NE555 timer consistently exhibits stable frequency oscillation, maintaining operational frequencies crucial for accurate vehicle detection. For instance in Figure 6 (a), the NE555 timer oscillates around 7 kHz with a voltage of approximately 3.46 V under normal conditions. However in Figure 6 (b), upon detecting a vehicle, these parameters shift, demonstrating a frequency drop to around 1.852 kHz and a corresponding decrease in voltage to 471 mV. This frequency modulation precisely identifies changes in the parking spot's inductance caused by the presence of a vehicle, affirming the NE555 timer's robust performance in supporting the smart parking system's core functionality through precise frequency modulation.

In parallel with frequency modulation, the NE555 timer generates square wave output signals with amplitude directly influenced by operational parameters such as supply voltage (Vcc) and load characteristics. Throughout testing, the amplitude of the output signal remained sufficient to drive subsequent stages of the detection circuitry, ensuring reliable operation across varying loads and environmental conditions. The consistency of signal amplitude underscores the NE555 timer's capability to interface effectively with downstream components, including operational amplifiers (op-amps) and microcontrollers, without compromising detection accuracy.

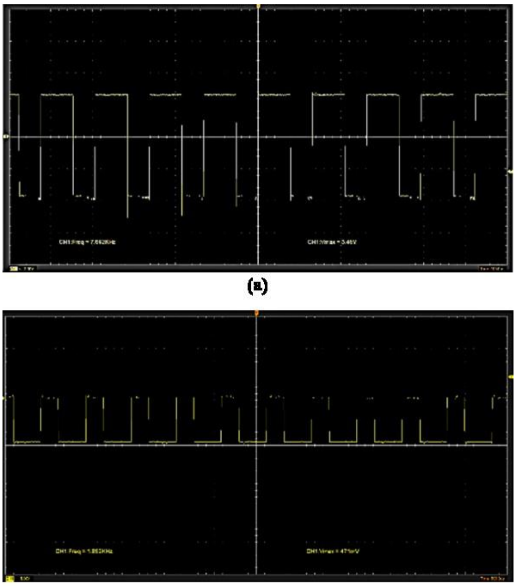

Fig. 6. Frequency analysis of the sensing coil, a) frequency trend when no car detected, and b) frequency trend when car detected

4 Conclusion and Further Improvement

This project presents a comprehensive solution to urban parking management, particularly suited for UiTM parking spaces. Integrating NE555 timers, operational amplifiers, NEO-6M GPS modules, SIM900A GSM modules, solar panels, and CN3791 charger modules, the system achieves real-time detection and communication of parking spot availability. Rigorous testing validated its accuracy and reliability, demonstrating significant improvements in parking efficiency through precise data collection. Addressing challenges such as weather resilience and signal interference, the system proved robust and scalable, with future plans to enhance sensor accuracy and incorporate predictive analytics for smarter traffic management. This project underscores the transformative potential of sensor technologies in advancing sustainable urban infrastructure, reducing congestion, and enhancing overall livability. However, the system requires a GSM module that supports reliable networks such as 4G or 5G for data transfer to an IoT cloud server.

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