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Internet of things enabled parking management system using long range wide area network for smart city

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ABSTRACT

As the Internet of Things (IoT) evolves, it paves the way for vital smart city applications, with the Smart Parking Management System (SPMS) standing as a prime example. This research introduces a novel IoT-driven SPMS that leverages Long Range Wide Area Network (LoRaWAN) technology, termed as IoT-SPMS-LoRaWAN, to surmount typical restrictions related to communication range, energy usage, and implementation cost seen in traditional systems. IoT-SPMS-LoRaWAN features intelligent sensing nodes that incorporate an Arduino UNO microcontroller and two sensors—a triaxial magnetic sensor and a waterproof ultrasonic sensor. These components collaboratively detect vehicle occupancy and transmit this data to the server via a LoRaWAN gateway. Notably, the integration of LoRa technology enables extensive network coverage and energy efficiency. Users are provided with real-time updates on parking availability via the accessible AllThingsTalk Maker graphical user interface. Additionally, the system operates independently, sustained by a solar-powered rechargeable battery. Practical testing of IoT-SPMS-LoRaWAN under various scenarios validates its merits in terms of functionality, ease of use, reliable data transmission, and precision. Its urban implementation is expected to alleviate traffic congestion, optimize parking utilization, and elevate awareness about available parking spaces among users. Primarily, this study enriches the realm of smart city solutions by enhancing the efficiency of parking management and user experience via IoT.

1. Introduction

Parking availability in almost every suburban area is always limited, and searching for a vacant parking spot is time-consuming and leads to traffic congestion, air pollution, fuel waste, and the frustration of drivers [1]. Moreover, the development in the cities leads to many traffic problems, where searching for parking slots can cause up to 30% of inner-city traffic congestion [2,3]. On the contrary, some parking lots have low utilization rates and are vacant most of the time, but no drivers reach such parking lots because of the lack of real-time information [4]. Thus, parking slot availability has become a widespread problem in urban development, and recently, people's awareness of the importance of parking spaces has increased. Accordingly, using a smart parking management system that gathers real-time information about parking spots around the city and makes them available to the public is necessary [5]. Thus, this system can help match drivers to the available parking slots, save their time, improve utilization of parking spots, reduce the cost of parking management, and relieve traffic congestion [6].

Considering the aforementioned issues, various smart parking systems (SPSs) are founded in the market [7]. SPS comprises barrier gates, controls accessibility, and automates parking systems. Therefore, SPS helps to overcome illegal parking, and traffic congestion problems, waste time in finding a parking space, and optimization of the parking capacity [8]. Sensors for detecting vehicles are usually placed in parking spaces to update the drivers with the parking status and allow them to secure a vacant parking space conveniently [9]. Some systems also utilize access control (tickets or tokens) of the hassle-free payment mechanism to allow a vehicle to enter and exit conveniently. Most importantly, the development of the parking-guided system plays the biggest role in the newest SPS technology in public or private parking areas. To always offer the best system management, the system is continuously being further developed. Every year, ongoing developments of new features are to be added for successful and updated smart parking management. The reason is the influence of the Internet of Things (IoT) paradigm to automize and improve our daily lives by utilizing new technologies.

IoT utilizes various systems and protocols to connect multiple networks of devices and sensors to the Internet [10,11]. IoT involves the extension of Internet connectivity beyond standard devices to link

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everyday objects to be remotely monitored and controlled over the Internet. The IoT depends on smartphone applications to update data to a central server. Thus, IoT improves network scalability, data security, and transmission reliability and presents features, such as real-time analysis and event processing. IoT also provides historical data trends, alerts, and notifications; in addition, it collects device data and turns it into actionable insights [12,13]. The implementation of IoT applications and smart infrastructure has affected possibilities for parking. According to Ref. [14], parking operators should pay particular attention to customer experience, technology and data analytics, location management, efficient pricing systems, demand management, and robust cost management.

The concept of an IoT-based parking system uses sensors to monitor parking slots availability and a graphical user interface (GUI) for the end-user to check the parking slot status and book it accordingly [15]. Many IoT-based SPSs are proposed in the literature, and some are implemented in pioneer Smart City projects for improving urban life by considering several social, financial, and environmental aspects. However, most of them have limitations in terms of the microcontroller processing capabilities, the sensitivity of the detection methods, and the system interface. In addition, most of the implemented parking monitoring systems are locally operated and lack real-time information to the driver about where to find a parking space [16]. In addition, most of them are commonly used in either wired networks or short-range communication technologies (Bluetooth, ZigBee, Wi-Fi, and RFID). However, these technologies are not reliable in most scenarios of indoor and outdoor parking and have many issues related to interference, energy consumption, and limited resources. The evolution of smart parking has had many motivations, and among them is the utilization of long-range technologies, such as Long-Range Wide Area Network (LoRaWAN) [17,18]. Thus, in this study, we propose to implement LoRaWAN into the SPS.

LoRa is a patented technology for wireless communication of IoT and the LoRaWAN, which is a low-power and wide-area networking (LPWAN) protocol with an open specification that supports LoRa technology. The topology of LoRaWAN networks is star-of-stars with a gateway that forwards the data from the LoRa nodes to the IoT server [19]. The wireless communication channel between the nodes and the gateway goes through the LoRa physical layer, whereas the gateways and the IoT server are connected through LoRaWAN MAC Layer over a backbone IP-based network. The LoRa technology can be easily plugged into the conventional infrastructure to enable low-cost, low-data rate and battery-operated IoT applications [20]. The LoRa technology supports secure, two-way communication for IoT applications that scale to connect millions of potential devices. The LoRaWAN protocol was designed with authentication and encryption built into the specification itself for security purposes. Single-LoRa gateway devices can handle thousands of end devices or nodes. Compared with other IoT, LoRaWAN is a low-power, long-range network and has secure data transmission, allowing the system to work for a long time and reach any device at a longer distance. This technology may be applied to big spaces of parking lots.

The conventional parking systems failed to provide reliable and real-time information. Data unreliability and low robustness in data transmission because of the frequent link failure cause difficulties in data collection from malfunctioned sensors, resulting in miscommunication with the management server and end-users. Furthermore, the high cost of the market-available smart sensing units, implementation and maintenance cost, systems complexity, and energy consumption are among the issues in conventional systems. Therefore, these constraints should be tackled in any proposed solutions. In addition, more efficient, reliable, robust, cost-effective, maintenance-free, and easy-to-deploy smart parking units with IoT support should be developed for real-time information and data accessibility by drivers and management. The utilization of LPWAN, such as LoRa, NB-IoT, and SigFox, is still in its early stages in smart parking applications [21]. Hence, the development of smart sensing units for real-time parking monitoring and management is based on one of these most advanced wireless technologies highly in demand.

Overall, most of the SPS includes a sensing unit (controller and sensor) with a communication interface, power supply, and a management server. The on-site sensing unit is usually deployed in the parking spots to detect vehicle presence at the considered parking space. In some systems, Wireless Sensor Networks (WSNs) are used to manage the parking and notify end-users about parking slots availability through a mobile application GUI. Most of the related studies on parking management had constraints related to communication technology and IoT utilization. Although some systems applied the WSNs concept in parking monitoring, real-time data updating to the Internet is not yet supported. Hence, most of the existing SPSs operate locally with a limited area. From another perspective, a few studies applied the IoT concept for parking management systems but had some issues related to connectivity range, microcontroller processing capabilities, sensing accuracy, energy consumption, and cost.

This study aims to develop an IoT-based smart parking management system by utilizing LPWAN technologies. Smart sensing nodes using a LoRa communication interface with an embedded microcontroller will be developed and deployed in the parking lots for a real-time update of parking slots status to the IoT platform that will be supervised by the management office to allow drivers to find the vacant spots easily and efficiently using their smartphones. LoRa is selected because it maintains a wide range of network connectivity, consumes low power, uses a low data transmission rate, and is license-free sub-GHz. As expected, the IoT-based parking system will reduce traffic in the city, particularly in the holy sites and improve parking utilization and people's awareness of parking availability.

In this study, our emphasis is placed on creating advanced sensing nodes utilizing LoRa technology, comprised of dual sensors (ultrasonic and magnetic sensors). This design ensures efficient real-time information transfer and extended network connectivity range within the targeted area. The sophisticated and efficient sensing units will consequently update data to the IoT cloud platform, granting real-time access to both drivers and parking management. A LoRa gateway will be employed for simultaneous data collection from multiple sensors and subsequent transmission to the Internet. An IoT dashboard/GUI will be fashioned to facilitate real-time parking data collection for drivers and management personnel.

In pursuit of these objectives, we design and fabricate a Smart Parking System (SPS) predicated on LoRaWAN capable of reaching up to a 10 km range and transmitting sensor data to users. Users will be empowered to monitor parking space data from the AllThingsTalk Glance GUI at any given time and location. The unique contributions of this work encompass the following:

(i) Development of an SPS employing LoRaWAN-based IoT technology, capable of providing real-time information about the availability of both indoor and outdoor parking spaces. This development is projected to enhance data transmission reliability, diminish implementation costs, and extend the system communication range by enabling parking authorities to implement their own gateways for data collection and updates to the IoT server without incurring any data subscription charges.

(ii) Implementation of a smart sensing unit integrating a three-axis digital compass breakout board and a waterproof ultrasonic sensor, linked to an Arduino Uno with a LoRa shield and powered by a solar panel via a solar charger shield. This configuration is expected to boost data collection accuracy and operation sustainability of the developed sensing node.

(iii) Introduction of a novel algorithm for data collection from both sensors using the Arduino IDE, facilitating data acquisition scheduling and data forwarding via a custom-made LoRaWAN gateway. This algorithm allows interaction between both sensors, the gateway, The Things Network (TTN) platform, and the integrated AllThingsTalk GUI. The new algorithm ensures the

compatibility of all components to provide real-time information about vacant parking slots to drivers.
(iv) Fabrication and deployment of the smart sensing node and the LoRaWAN gateway along with their configuration in the open-source IoT platform, TTN.
(v) Validation of functionality and performance of the developed LoRaWAN-based system through practical use cases at Universiti Malaysia Pahang parking lots.

The remainder of this paper is structured as follows. Section II reviews the related literature. Section III expounds on the design and modelling of the sensor node along with the fabrication process. Section IV delves into the details of the developed LoRaWAN SPS architecture, its implementation, and its functionalities. Section V deliberates on the results, and finally, Section VI offers the conclusion of the study.

2. Related works

The advancement of SPSs has garnered attention from both academic and industrial sectors due to their financial, ecological, and visual effects. A variety of proprietary parking solutions, including SmartParking, PlacePod, and Sitraffic Scala, have emerged, offering features such as online reservation, fee processing, and dynamic parking maps. Nonetheless, their primary limitations are the expensive price point and restricted development potential for public developers, as they are not open-source. Numerous scholarly reviews have investigated, categorized, and examined the technical components of intelligent parking systems [22–25].

The range of associated articles tackles various topics such as application and user experience [6,26–28], pricing and agreements [29–31], and predicting availability and allocation [8,32,33]. Several criteria can be used to categorize these systems, such as parking environment, offered services, or primary sensing methods. Parking systems can be analyzed and grouped based on essential sensing techniques like wireless, mobile, and camera-based systems. This section will only focus on the most relevant smart parking solutions to the suggested approach in this article. These solutions employ wireless sensor-based systems that use LoRa as the system's network infrastructure, enabling extensive coverage and low power consumption.

Several studies [34–36] have demonstrated a proof-of-concept implementation for a Smart Parking System (SPS) using LoRa infrastructure. The implemented systems exhibited efficiency in energy, robustness, and scalability for large-city parking monitoring and management. In Ref. [37], an online reservation system was integrated with parking lots at Universitas Hasanuddin. Similarly, a LoRa-based SPS was developed in Ref. [38], which included sensor modules, a server module, a reservation application, and a third-party payment platform. This system was tested in Ningbo and Zhoushan, two cities in China's Zhejiang province, resulting in improved monitoring and booking capabilities. However, the LoRa communication's quality, security, and reliability were not evaluated in real parking lots with intricate urban settings.

In [39], researchers presented a smart parking solution that integrated Libelium smart parking sensors, LoRaWAN, and a Kubernetes cluster with MQTT and MongoDB. This combination improved the SPS's availability, scalability, and portability by addressing information sharing bottlenecks. The system stored all messages in a messaging server for further processing if the primary data collection server failed. Another smart parking solution with a pricing algorithm for maximizing revenue was proposed in Ref. [40], where the price was dynamically adjusted to balance the supply and demand of parking spaces while ensuring a minimum parking fee. This solution employed various sensors to detect vehicles and gather contextual and environmental data, utilizing edge cloud computing to reduce network load and gateway quantity.

Other studies aimed to enhance the interoperability of parking solutions. The system in Ref. [41] implemented an IoT Gateway Centric Architecture [42], enabling real-time interaction between supported sensor devices and/or actuators via the LoRa gateway using the LoRa network. The gateway then converted packets into a format acceptable by the server, eliminating the need for a network server to route packets. Received packets were parsed using Spring functions and processed with database data if required before being sent to users. The parking payment functions utilized the payment highway API. In Ref. [43], a novel Wise-IoT system framework was developed for global interoperability and mobility of IoT applications and devices, using different IoT infrastructures (including LoRaWAN) and interoperability layers. Implemented in Busan and Santander, the smart parking system in Santander could be used in various Busan locations and vice versa.

To preserve privacy in parking systems [44], proposed an enhanced LoRaWAN security protocol that provided basic connectivity functions and addressed security issues. This protocol prevented malicious network servers from compromising end-to-end security between a device and its application server. The protocol was tested using various tools, demonstrating its superiority over two handshake options in terms of network latency and signalling overheads. In Ref. [45], a new method using secure elements was proposed to safely store keys and process the LoRaWAN protocol. The secure element managed security functions like data encryption and message signing and an efficient integrity verification method was proposed for the main microcontroller unit based on Secure Element.

Most SPSs consist of a sensing unit (controller and sensor) with a communication interface, power supply, and management server. On-site sensing units are typically deployed in parking spaces to detect vehicle presence. Some systems use Wireless Sensor Networks (WSNs) to manage parking and notify users about parking slot availability via a mobile app GUI. Many studies on parking management faced constraints related to communication technology and IoT utilization. Although some systems applied the WSNs concept in parking monitoring, real-time data updating to the Internet was unsupported, and most existing SPSs operated locally within a limited area. A few studies applied the IoT concept for parking management systems but faced issues related to connectivity range, microcontroller processing capabilities, sensing accuracy, energy consumption, and cost. In this study, we focus on developing smart sensing nodes based on LoRa technology, consisting of two sensors (ultrasonic and magnetic) to ensure efficient real-time information transfer and extended network connectivity. Smarter and more efficient sensing units will update information on the IoT cloud platform, accessible by drivers and parking management in real time. A LoRa gateway will collect data from multiple sensors simultaneously and send it to the Internet, and an IoT dashboard/GUI will enable real-time parking data access for drivers and management officers.

3. System modelling, design, and fabrication

3.1. Research methodology

In the early phase of the research, the focus is identifying what are the challenges to be confronted by the Smart Parking Management System. With the problems identified, research on potential solutions related to the issues had been conducted. All possible sensors, software used to develop mobile applications, and microcontrollers that have been used in the past and existing prototypes have been surveyed. This section explains how the research is conducted based on several phases and plans. This section includes the detailed proposed system components and the impact on solving the research gap and limitations. Fig. 1 depicts our research methodology flowchart.

In the first phase, we observe to find the limitations of SPSs in the market. Based on the investigation of the previous works, the research gaps are identified to be solved through the proposed system. Then, we proposed a smart sensor node that combines the IoT paradigm based on the LoRaWAN technology with the parking management system. After the equipment and materials for SPS are surveyed, the suitable components for harsh weather and strong feature are chosen to ensure that these materials can achieve the objectives in the modelling phase. A

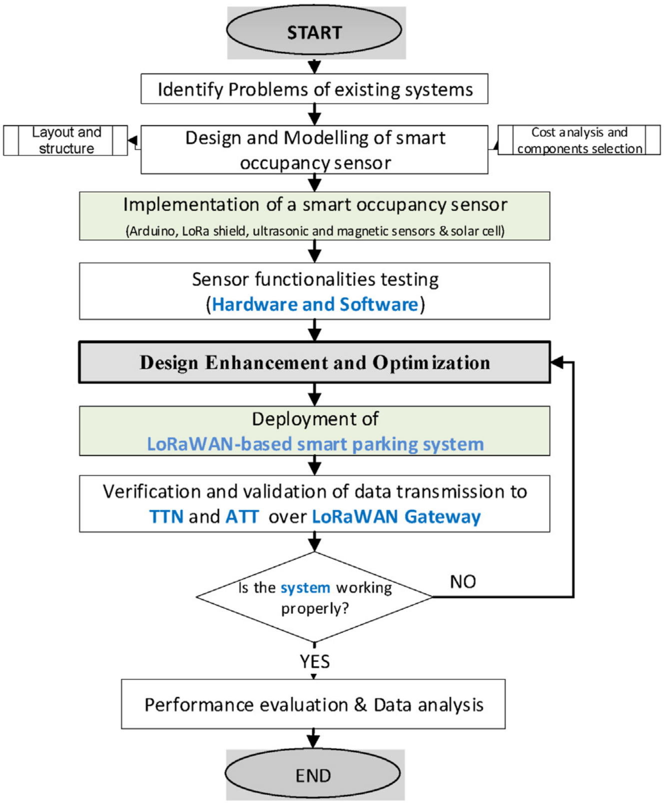


Fig. 1. Flowchart of research activities.

virtual parking lot plan layout is designed as shown in Fig. 2 to decide about the place of sensors, gateway, and parking area. Only one LoRaWAN gateway will be implemented to receive all the information from the sensor as its range can reach up to 10 km. The sensor will be implemented on the ground for each parking lot. A LED light is installed on the ceiling for each parking lot, which turns green when there is no vehicle in the parking lot. The light turns red when there is a vehicle parked inside. The LED light is implemented for local indicator purposes. LoRa is chosen as a communication module for SPS. A microcontroller with a LoRa interface is used to build the smart sensor node, and an ultrasonic sensor with a three-axis magnetic sensor is used for vehicle detection. Raspberry Pi has been utilized as a gateway to provide fast data analysis, thereby, speeding up the uploading of information to the cloud. The gateway will be updated on the data about parking availability in real-time to the IoT platform to be accessed by management and drivers. After that, the enhancement optimization phase was taken place via many tests virtually and physically. The design and modelling phase is followed by the development phase of the smart sensing unit to be installed in the parking spots. The proposed smart sensor is implemented as an individual unit. The design for the electronic circuits and schematic diagrams has been done by using suitable software. Then, the circuit connection among all the required components is installed on the breadboard for the initial stage.

Then, we developed coding to achieve the targeted system workflow. This process was followed by the design of the sensing node enclosure to finish the product and assemble all components as a unique and compact smart sensing unit. After that, several nodes' prototypes can be developed and deployed to form a smart parking testbed that collects data from multiple nodes about vacant parking slots in the area under the test and updates information to the cloud. The verification and validation of the entire network will be performed. Improvement is also performed when needed to ensure system functionality and its effectiveness. The test is repeated until the device is ready for practical implementation. When the effectiveness of the system is proved via the testbed, the product will be finalized, and a series of experiments will be carried out on the final prototype to evaluate its performance and analyze the collected data to report the main findings.

3.2. *System architecture*

Fig. 3 shows an overview of the system architecture, where the Arduino UNO microcontroller in the proposed system gathers data from the three-axis magnetic and ultrasonic sensors. This microcontroller can collect data and send it to the IoT server by the attached LoRa module. The node is powered using a rechargeable battery that is charged by using a solar panel through a solar charger shield. TTN is an open-source and secure LoRaWAN IoT server that is selected to receive the data payloads from the LoRaWAN gateway. The data transmission from the smart occupancy sensor will be verified to TTN and then integrated into AllThingsTalk Maker. The users can remotely monitor the parking services information available using Internet-connected devices. Both sensors will begin to simultaneously collect data on the parking space to ensure data accuracy. Once a car occupies the parking lot, it sends information right away to the TTN server through the LoRaWAN gateway. The TTN console collects all the messages from the gateway, filters out the duplicate information, and then forwards this information to the integration platform AllThingsTalk Maker. Immediately, a red LED will light up if the car is within a 50-cm radius. Otherwise, the green LED will continuously light up until the next car triggered the sensor. The red LED will turn green if the car left the parking spot. All the information will be

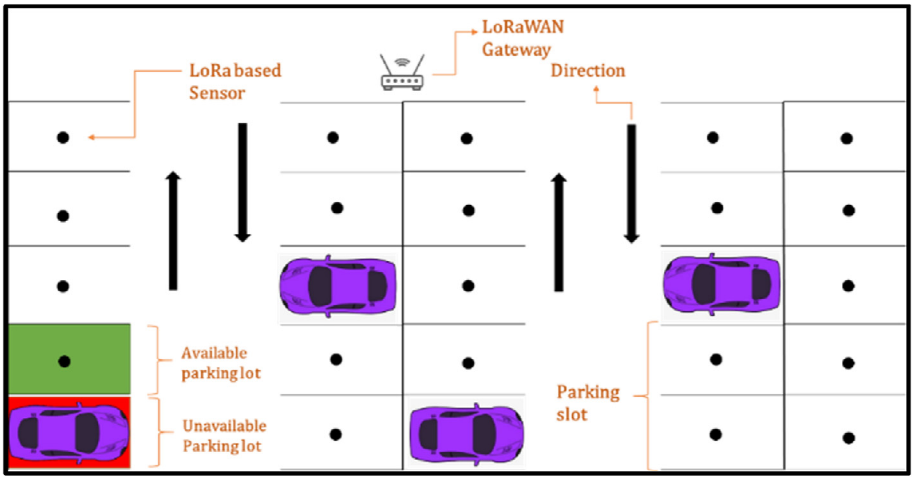


Fig. 2. Parking lot plan layout (top view).

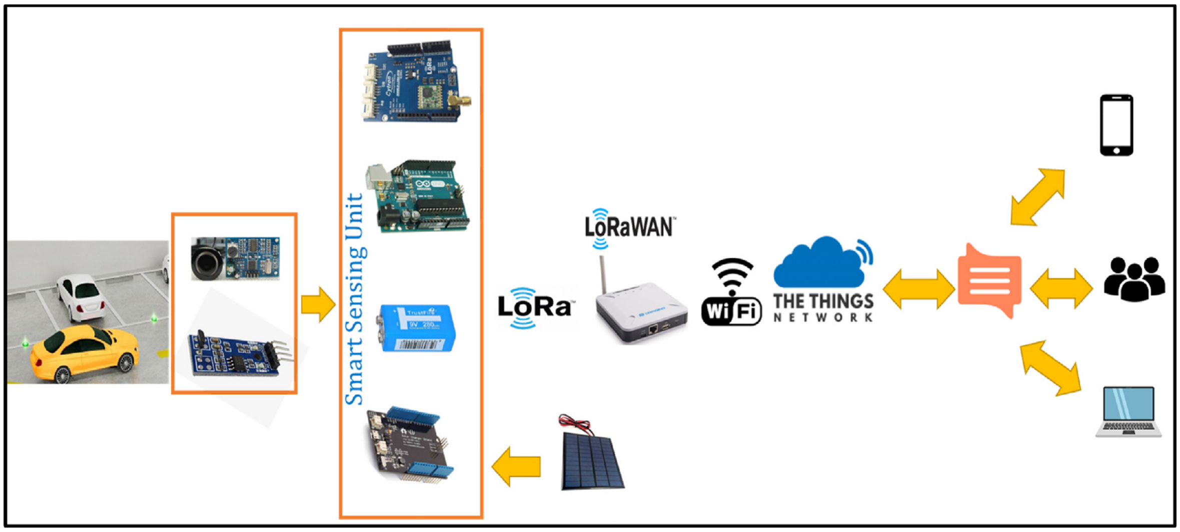


Fig. 3. Overall System architecture.

synchronized with the GUI, and drivers can conveniently find vacant and occupied parking spaces in real time. The duration of parking for each car can be estimated using the ultrasonic sensor timer from the time the red LED lights up until it turns green again. This time can be used to estimate the parking charges. Thus, drivers will find a more convenient way of monitoring parking status, a greener technology advancement experience, and better time management from the automated parking service provider.

3.3. *Components selection*

The selection of the components required for our system was made after thorough research into similar studies, projects, and datasheet specifications. We aimed to ensure the utmost functionality, compatibility, and efficiency, which drove our choices of hardware and software.

The hardware components were selected based on their unique features and abilities to fulfil the functions required by our system. The Arduino Uno Rev3 was chosen for its flexibility, simplicity, and strong community support, making it an excellent base for our smart sensor node. The LoRa-RFM Shield was selected for its superior long-range communication capability, critical for data transmission in our SPMS. The Solar Charger Shield v2.2 and the Solar Panel were included to provide a sustainable, autonomous power source, a necessity for the stand-alone operation of our system.

The three-axis digital compass breakout board (QMC5993L) was incorporated for its accuracy in vehicle detection, and the Waterproof Ultrasonic Module (JSN-SR04T) was chosen for its effectiveness in outdoor conditions and durability in various weather scenarios. The 3.7 V LiPo rechargeable battery was chosen for its high energy density and rechargeable nature, perfectly complementing our solar power setup.

For the software components, Fritzing software and Proteus Stimulation were selected for their usefulness in electronic design and circuit simulation, respectively. Arduino IDE software, given its compatibility with our chosen microcontroller, was a logical choice for coding and debugging. The Things Network (TTN) server was selected for its widespread use and compatibility with LoRaWAN, and AllThingsTalk Maker and Glance were chosen for their user-friendly interfaces, allowing for efficient data display and interaction. Finally, Solidwork software was chosen for its extensive capabilities in 3D modelling, vital for the design and fabrication of the sensor node.

After the careful selection of these components, we successfully designed and fabricated the sensor node, subsequently installing the LoRaWAN gateway, hence paving the way for our IoT-SPMS-LoRaWAN system's functionality.

3.4. *Sensor circuit design*

Fig. 4 shows the virtual circuit designed using Fritzing Software. The sensor node is equipped with a three-axis digital compass breakout board, which acts as a magnetometer to detect the presence of the metal (car) and a waterproof ultrasonic sensor to detect the distance and time taken by the car to use the parking lot. When the sensors gather the required data, one of the LED lights will light up, satisfying the condition predetermined automatically. The update of parking lot status along with the locations will eventually be displayed on the AllThingsTalk GUI. This real-time update will help the drivers to reduce the time and fuel consumed by wandering around. The controller of the smart parking sensor is powered by a 5-V USB power source, a 3.7-V rechargeable Lipo battery, and a photovoltaic array to ensure the continuity of the system's operation. The LoRa-RFM Shield and Solar Charger Shield v2.2 are stacked together on top of the Arduino.

Fig. 5 shows the simulation of the ultrasonic sensor replacing the waterproof ultrasonic sensor because of the limited Proteus library. Only the codes for the waterproof ultrasonic sensor were simulated. The distance is fixed to 20 cm in the coding for the red LED light to turn on. Otherwise, LED green will light up, indicating that the space is not yet taken. After completing the simulation, we connect the system components to the Arduino, which is programmed through the Arduino IDE software. In the beginning, the code was implemented only through virtual simulation using different components with similar properties. As we cannot fully utilize the Proteus software, the three-axis compass breakout board was tested physically using the Arduino UNO serial monitor. Experimentally, we tested the circuit several times before proceeding with the next process. In this phase, we focus more on the proof of concept and the compatibility testing of the selected components to work together in the proposed smart sensing unit.

3.5. *Smart sensor model fabrication*

The node enclosure layout has been designed, as shown in Fig. 6(a). Three-dimensional printing is used to build the enclosure of the sensor node. The rough design of the enclosure is sketched by considering the height of the stacked modules inside the nodes as the tallest height and the PCB and battery layout inside as the length and width of the enclosure. The measurements taken were in mm units only for the inner part, and 5 mm was added considering the thickness of the enclosure. A sketching software called Solidwork is used to obtain a real view of the enclosure.

This model consists of the top part, which can be detached from the bottom part to ease the placement of the components inside. The top part

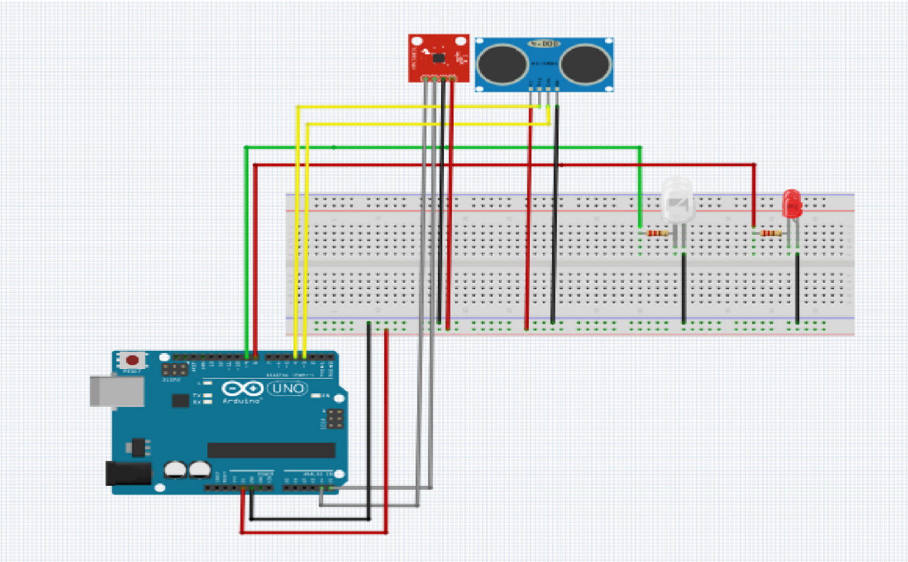


Fig. 4. Sensors implementation on breadboard.

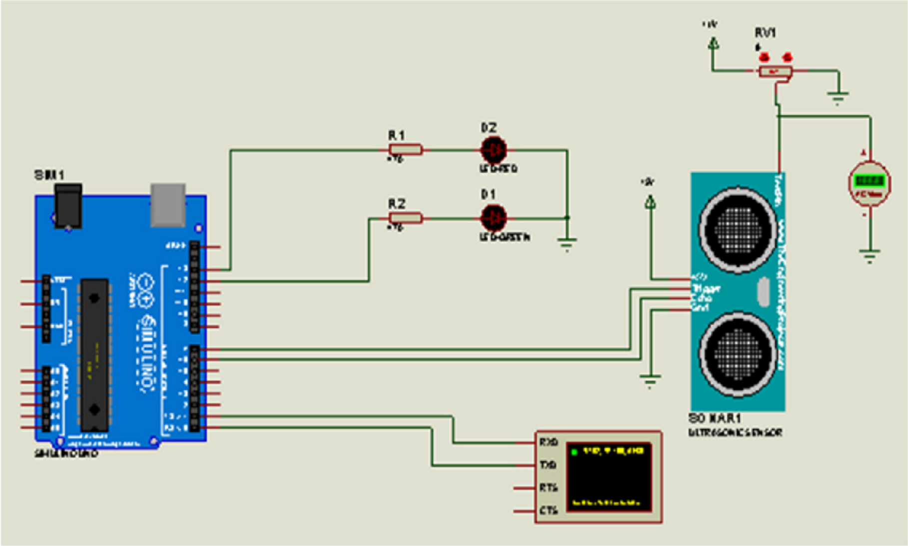


Fig. 5. Proteus simulation of the ultrasonic sensor.

is designed to be tightly closed with the bottom part as shown in Fig. 6(b). This part can be closed tightly and fully covered. The enclosure is waterproof and can keep the components safe from the surrounding conditions. The enclosure is made of PLA Filament which will not intercept or disturb the signal transfer of the sensors. This material can stand a temperature up to 190 °C. Given that we only use the enclosure for a sample prototype, we fix the infill to 30% with the total weight after printed is 514 g for the enclosure only. We use sandpaper for a smoother finish of the final product. The material is waterproof, but to ensure that no water can come in through the holes of the top part, a transparent plastic cover is added and glued using a hot glue gun, specifically to protect the three-axis compass breakout board, which is not waterproof. The other components that have been soldered and connected to their respective part are then fixed to the inner enclosure using silicon. The prototype is screwless, so the reading of the sensor is not affected by anything in the enclosure. A better design can be implemented, such as a smaller size, no sharp edges for the top and bottom parts, and a higher infill rate to withstand greater weight and pressure whenever it encounters the car.

Fig. 7 shows the top view of the end node exterior after soldering all the components. The solar panel is placed on the top to ease the process of battery charging by absorbing the sunlight. The antenna of the LoRa shield is placed on the left side of the enclosure to avoid any signal interruption. The ultrasonic sensor and magnetometer are placed on the top of the enclosure, and a transparent layer is placed on the magnetometer to make it more waterproof. Two green and red LEDs are used to locally show the status of the parking lot.

4. System development and implementation

In this section, the development and implementation of the IoT LoRaWAN-based parking management system are explained. After performing individual testing for various components of the proposed system, the implementation of the proposed design was carried out. The implemented IoT-SPMS-LoRaWAN was started by combining all sensors with the microcontroller and LoRa shield as one smart sensing unit to be placed in the considered parking spot. This phase includes system testing, enhancement, and finalization and also covers software development.

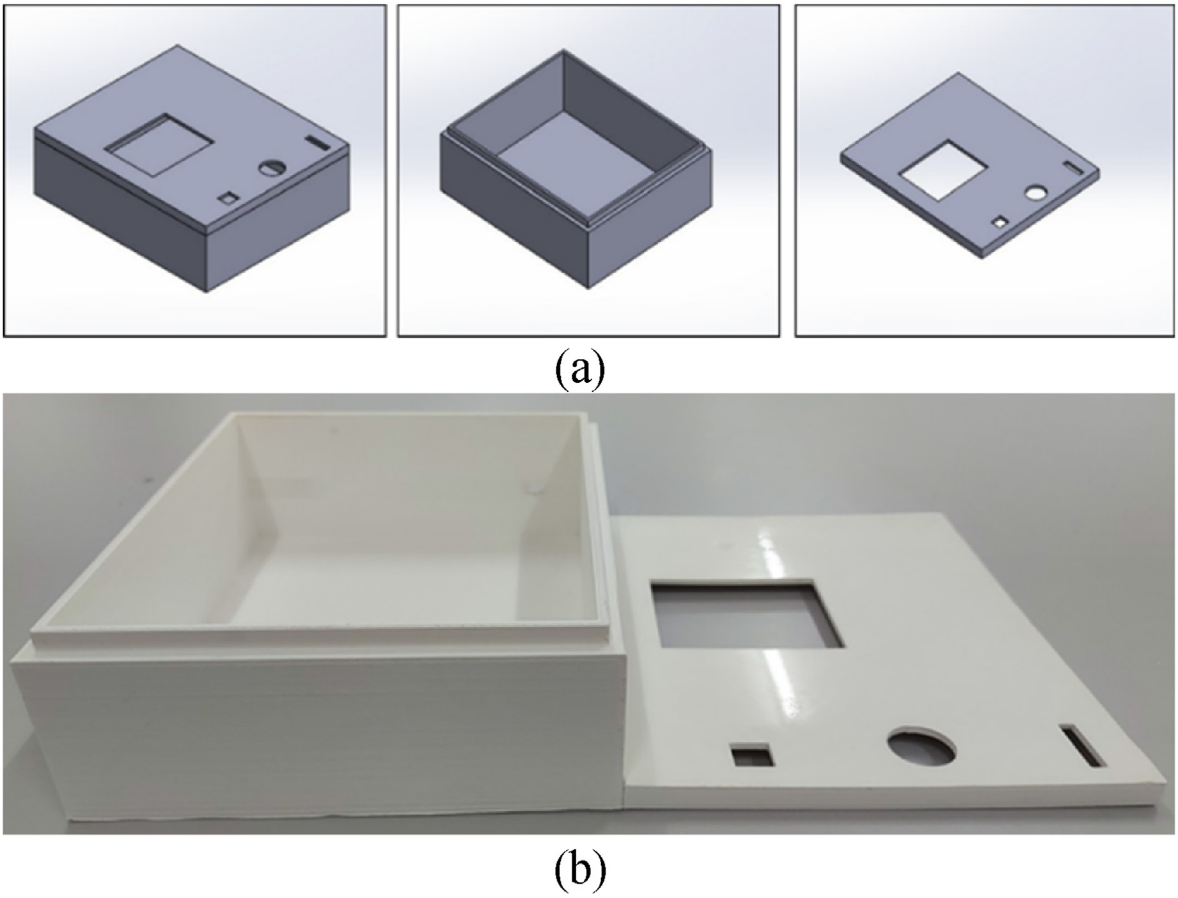


Fig. 6. (a) Enclosure designed with Solidwork Software (b) End Node Enclosure.

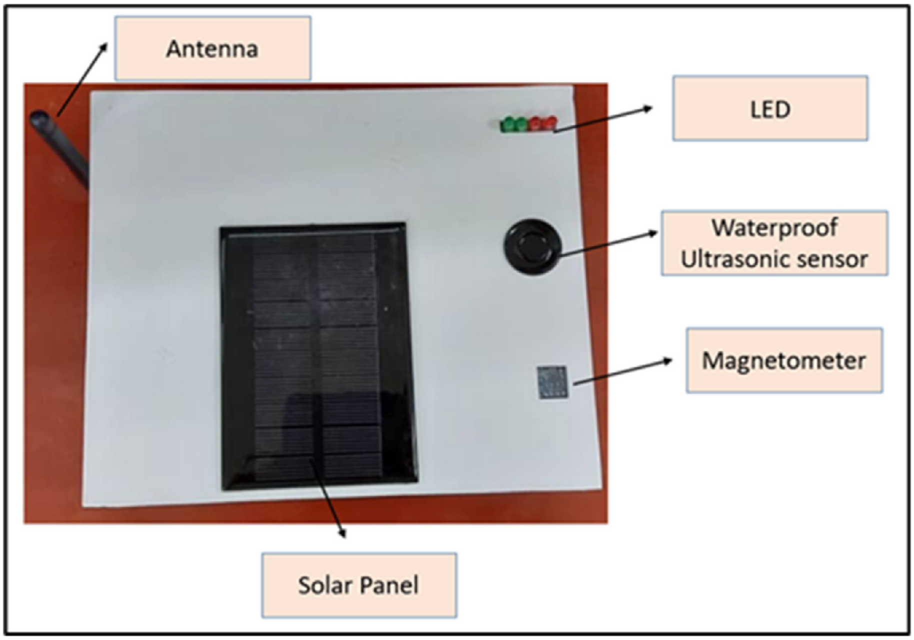
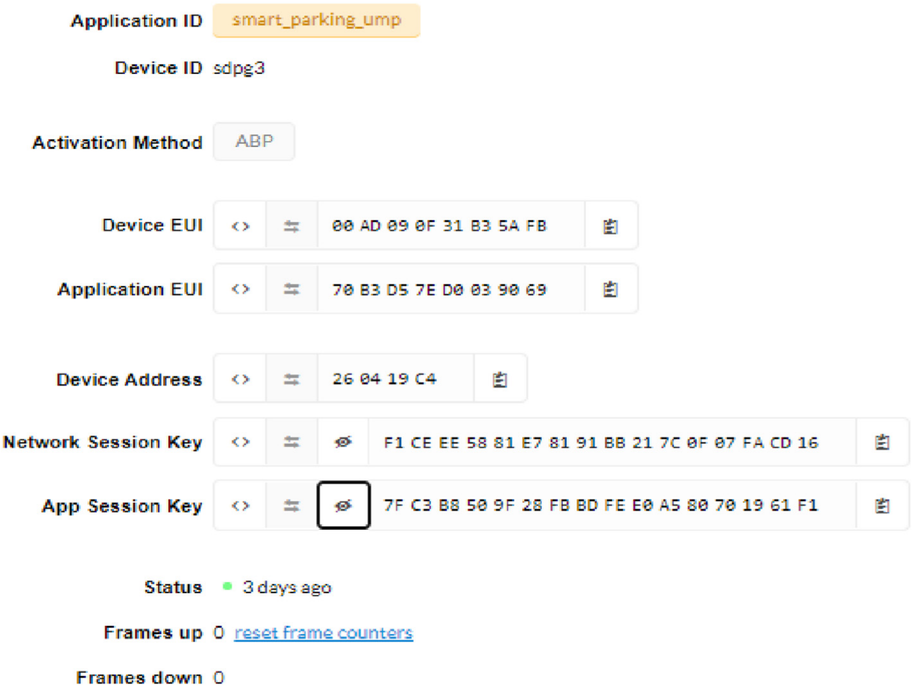


Fig. 7. Top view of end node exterior.

4.1. Functionality testing and enhancement

The verification of the system functionality was conducted, and the design was enhanced and optimized if necessary. This stage is vital to meet the design objectives of the system and identify and fix hardware and software problems. These verification steps are repeated until a successful implementation is accomplished. For example, before starting the real placement of the smart sensing node in the parking slots, the system inputs and outputs should be measured in the LAB and ensure that the measurements are satisfactory. After compiling the coding libraries of the sensors, actuators, and interfaces into Arduino Uno, sensing unit functionality and communication capability were locally tested using a serial monitor first and then checked in the IoT platform. The code testing is repeated until the desired result is obtained. The configuration of the sensing node in the TTN platform either as an application or device also has been carried out to generate a unique identifier to receive the data from the smart sensing unit as shown in Fig. 8. This figure shows the connectivity of the device through the TTN server. Notably, the device address, network session key, and application key are the same as in the Arduino Uno coding. The application was integrated with the TTN, and a unique ID was generated for the application. The LoRaWAN gateway configuration is also set up in the TTN platform.

Once the device is correctly configured and linked to the LoRaWAN gateway and TTN server, the data can be uploaded to the IoT server as soon as the device is turned on. The gateway receives the data and displays it in the TTN server as shown in Fig. 9. Here, the payload is



Application ID smart_parking_ump
Device ID sdpg3

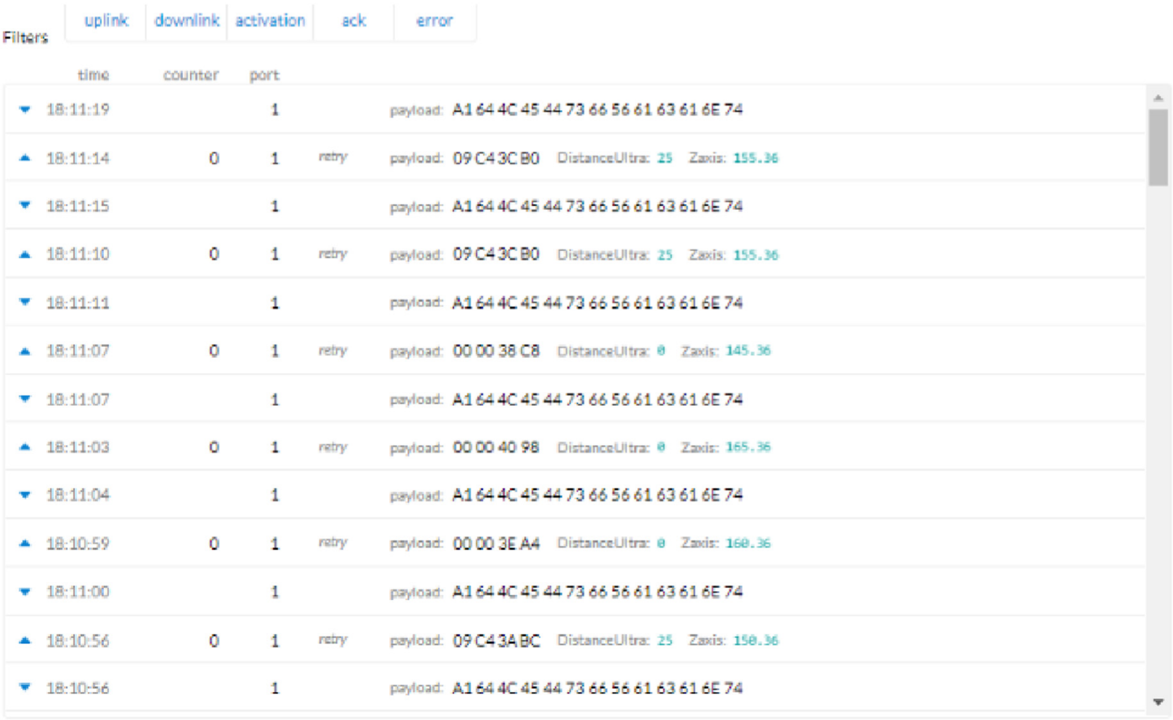
Activation Method ABP

Device EUI 00 AD 09 0F 31 B3 5A FB
Application EUI 70 B3 D5 7E D0 03 90 69

Device Address 26 04 19 C4
Network Session Key F1 CE EE 58 81 E7 81 91 BB 21 7C 0F 07 FA CD 16
App Session Key 7F C3 B8 50 9F 28 FB BD FE E0 A5 80 70 19 61 F1

Status ● 3 days ago
Frames up 0 reset frame counters
Frames down 0

Fig. 8. Device overview of TTN Server.



	time	counter	port		
▼	18:11:19		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74
▲	18:11:14	0	1	retry	payload: 09 C4 3C B0 DistanceUltra: 25 Zaxis: 155.36
▼	18:11:15		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74
▲	18:11:10	0	1	retry	payload: 09 C4 3C B0 DistanceUltra: 25 Zaxis: 155.36
▼	18:11:11		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74
▲	18:11:07	0	1	retry	payload: 00 00 38 C8 DistanceUltra: 0 Zaxis: 145.36
▼	18:11:07		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74
▲	18:11:03	0	1	retry	payload: 00 00 40 98 DistanceUltra: 0 Zaxis: 165.36
▼	18:11:04		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74
▲	18:10:59	0	1	retry	payload: 00 00 3E A4 DistanceUltra: 0 Zaxis: 160.36
▼	18:11:00		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74
▲	18:10:56	0	1	retry	payload: 09 C4 3A BC DistanceUltra: 25 Zaxis: 150.36
▼	18:10:56		1		payload: A1 64 4C 45 44 73 66 56 61 63 61 6E 74

Fig. 9. Successfully received data at the TTN platform.

Network
The Things Network

Device EUI
00-AD-09-0F-31-B3-5A-FB

Application ID
smart_parking_ump

Device Address
260419C4

Network Session Key
F1CEEE5881E78191BB217C0F07FACD16

Application Session Key
7FC3B8509F28FBBDFEE0A580701961F1

Fig. 10. Successfully received data at the TTN platform.

displayed in a readable form and translated using a decoder function accordingly to display the obtained readings from the sensors. The next step is to integrate the data into a user-friendly interface. An ATT Maker is created and linked to the gateway. Again, using the same information in TTN and the gateway, ATT was able to be connected and integrated as shown in Fig. 10. The device EUI information is taken from the TTN server. Then, the ATT Maker is linked to the gateway by inserting the gateway ID in the ATT Maker. The name of the gateway and its status currently serving the ground or device is connected to ATT Maker. We have conducted many tests under various conditions, such as outdoor, windy, and rainy days.

4.2. System operational procedure

The developed smart sensing units are placed in the parking lots. Nodes are powered on, and the solar panel will charge the battery when the parking spot is empty. If a car is parked, the node will be powered using a rechargeable battery. The magnetic and ultrasonic sensors will detect the presence of the vehicles above the sensing unit. The collected data by the sensors will be processed in the Arduino to be sent as payloads using the LoRa shield to the LoRaWAN gateway and uploaded to the TTN. In our coding, we have developed an algorithm to gather the information from the sensors and passed to the cloud as in *Algorithm* 1.

When a user wants to access this SPS, the user's mobile phone or laptop needs to connect to the Internet to view the real-time information of the parking lot via ATT Glance. The gateway placed in the parking area needs to be connected to the Internet as well to receive and send data to the network server. The smart parking node will start to send the data detected by the waterproof ultrasonic sensor and magnetometer to the TTN through the gateway. If the distance of the waterproof ultrasonic sensor is less than 40 cm and the value of the z-axis which is the magnetic field strength is more than 225, then the red LED (occupied) will light up as a local indicator in the parking lot. If not, then the green LED will light up, which means that the parking lot is vacant. Drivers can explore this information through the ATTM GUI using Internet-connected devices. Fig. 11 shows the detailed steps of the IoT-SPMS-LoRaWAN.

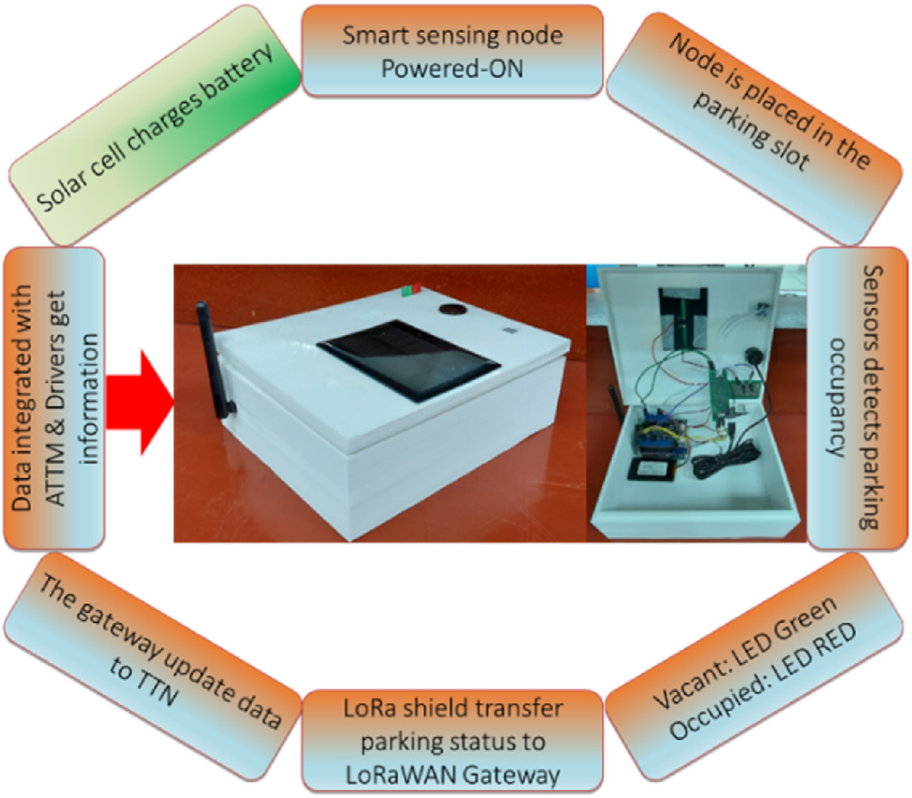


Fig. 11. System operational procedure.

Algorithm 1. Smart Parking System based on LoRaWAN

```
Require: Monitor parking lot occupancy and vacancy status
Ensure: Real-time parking monitoring (ultrasonic sensor and magnetometer)
Install LoRaWAN Gateway & connect to the Internet
Register the Gateway in the TTN Console (GW ID, Frequency Plan, router, GW key)
Create IoT-SPMS-LoRaWAN Application in the TTN Console (App. ID, App. EUI,
  TTN-Handler)
Register LoRa Node under IoT-SPMS-LoRaWAN Application (Dev. ID, Dev. EUI, App
  Key, App EUI)
Define Device Activation Method (ABP)
Get Network Session Key & App Session Key & Device Address
Define Libraries for multi-sensor smart LoRa node & TTN
Define LoRa-Node pin mapping ➲ For sensors & LoRa connection
Set LoRa configuration parameters
$D \leftarrow$ Distance value ➲ B25 sensor
$Z \leftarrow$ z-axis magnetometer value ➲ ACS712 Sensor
Initialize IoT-SPMS-LoRaWAN ➲ System Powered ON at $t = 0$
for each round do
    Get $D$, $Z$
    Multiply each reading by 100 ➲ Represent each sensor by 2 words
    Split both words (16 bits) into 2 bytes of 8 bits
    Encode all bytes into ONE Payload of 4 bytes
    Establish a connection between LoRa Node & LoRaWAN GW
    Update status of the node in TTN Server (online)
    Send data to LoRaWAN GW
    Upload data to TTN Server over the Internet
    Decode the received Payloads to retrieve original sensors readings
    Integrate data into ATTM Web-based dashboard
    Synchronize data with ATTM mobile App. using Smartphone
    if $Z > 225$ && $D < 40$ cm then
        Red LED lights up and updates “occupied parking” ➲ ATT Glance
    else Green LED lights up and notify “vacant parking” ➲ ATT Glance
end for
Drivers monitor parking status in realtime using their devices
END
```

4.3. Sensor node implementation

In the practical implementation of the designed sensing node, we uploaded all the developed coding into Arduino Uno, connected to LoRaWAN using the LoRa shield, and supplied power to the system using the rechargeable battery and solar panel that is connected to the solar shield. All these modules were stacked on top of each other and placed inside the node enclosure. From the bottom, the arrangement is as follows: Arduino Uno, LoRa shield, and solar shield. A magnetometer and waterproof ultrasonic sensor were soldered to PCB 1, whereas LEDs and resistors were soldered to PCB 2. The battery used a 3.7-V LiPo rechargeable battery, and the solar panel is a 5-V solar panel. All the components were then connected according to the pins and ports defined in the Arduino Uno sketch. To ensure that the data transmission is efficiently transferred from sensors to the gateway receiver, the antenna is placed outside the enclosure. A hotspot was used to connect to the LoRaWAN gateway to the Internet, which is placed in the office that is 1 km away from the parking lots. From here, all data can be seen on the TTN server website, which receives data every 5 s when the device is connected to the gateway. The number of packets transmitted can be reduced and scheduled based on the demand to reduce the usage of the power supply.

The obtained data from the implemented waterproof ultrasonic sensor and magnetometer are updated on the TTN server. After the data were integrated into the ATT Maker, the information can be viewed in a more readable form through ATT Glance GUI which is available only for the mobile version of ATT Maker. The web version of ATT allows editing of the rules that are used to control the virtual actuator that indicates the occupancy/vacancy status of the parking. The web version of ATT Maker must be linked to the sensing node that is configured in the TTN platform application first as stated earlier. When the gateway is connected to the device, the TTN server and ATT Maker will collect the data and display the parking status in ATT Glance accordingly.

4.4. System verification and data collection

A series of experiments were designed and implemented to capture data from both the magnetometer and the waterproof ultrasonic sensor. This data was vital for verifying the system's accuracy and calibrating the sensor outputs. We used three distinct conditions to position the sensing unit, allowing us to observe changes in the gathered data and establish threshold values. Fig. 13 visually depicts the prototype placed in both vacant and occupied parking lots, illustrating the three testing scenarios.

Each scenario was meticulously designed to ensure uninterrupted sensitivity and LoRaWAN signal throughout the tests. In the first scenario, we considered two subcases within a vacant parking lot: one with neighbouring vehicles and another without, as depicted in Fig. 12(a).

Next, in the second scenario, we tested the unit with a vehicle occupying the parking lot. We placed the unit in three different positions on the ground of the target lot as demonstrated in Fig. 12(b). Although the signal strength was noticeably better at the front and rear positions, we selected the middle position for its balanced data accuracy across a variety of car lengths. Furthermore, the sensors were most efficient at detecting distance and metal objects from this position. We observed that the readings taken from the front and back of the car were sometimes unclear, which could potentially skew performance evaluations.

In our final scenario, we recorded data from both the magnetometer and waterproof ultrasonic sensor while the parking lot was occupied. Here, we placed the prototype under five different vehicles—Toyota Yaris, Proton Saga, Perodua Myvi, Santria Neo, and Honda City—as demonstrated in Fig. 12(c). The data was collected every 10 min for subsequent analysis and comparison, enabling us to thoroughly evaluate the system's performance across diverse situations.

Furthermore, the value of combining a magnetic sensor with an ultrasonic sensor is evidenced during testing of the sensing unit in proximity to non-metallic objects. Despite a plastic object satisfying the distance threshold criteria by being placed close to the sensor, the magnetic strength did not reach the designated threshold value (225 T). Consequently, the reported parking status remained 'vacant,' and the green LED remained illuminated, confirming the absence of a vehicle. Sensor readings were observed and logged from both the TTN server and the ATT Maker. This experiment was reproduced across all case scenarios and with each vehicle type to assess the data transmission performance.

Fig. 13 shows the graph of magnetic strength obtained from the Z-axis magnetometer in different scenarios. The range of vacant vehicles in the parking lot was much lower than the range of occupied vehicles in the parking lot. The minimum value of magnetic strength obtained from the magnetometer for vacant vehicles was 132 T, whereas the maximum value was 146 T. Meanwhile, the value of magnetic strength for occupied vehicles ranges from 112 to 137 T. The threshold is set at the value of 225 T in the system coding. When the value is lower than 225 T, the parking lot is vacant. On the contrary, when the value of the magnetometer is above 225 T, the parking lot is occupied. Comparing the values of the z-axis magnetometer for both conditions of vacant parking, the magnetic strength was not affected by the vehicle beside the selected parking lot. Considering that the axis is only pointed upward, the surrounding objects will not disrupt the data acquisition process.

Fig. 14 represents the data procured from the waterproof ultrasonic sensor under diverse conditions of the target parking lot. Prior to initiating the experiment, the threshold for the waterproof ultrasonic sensor was pre-established at 40 cm within the system code, a requisite for the optimal functionality of the prototype. The graph validates the appropriateness of the predetermined system threshold for the vehicle, as the distances gleaned from the various vehicles fell below 22 cm, as observed during the experiment. It can be discerned that when the value registered by the waterproof ultrasonic sensor exceeds 40 cm, the parking lot is deemed vacant. Conversely, when the value falls below 40 cm, the parking lot is identified as occupied.

(a) Scenario I

(b) Scenario II

(C) Scenario III

Fig. 12. Data collection scenarios.

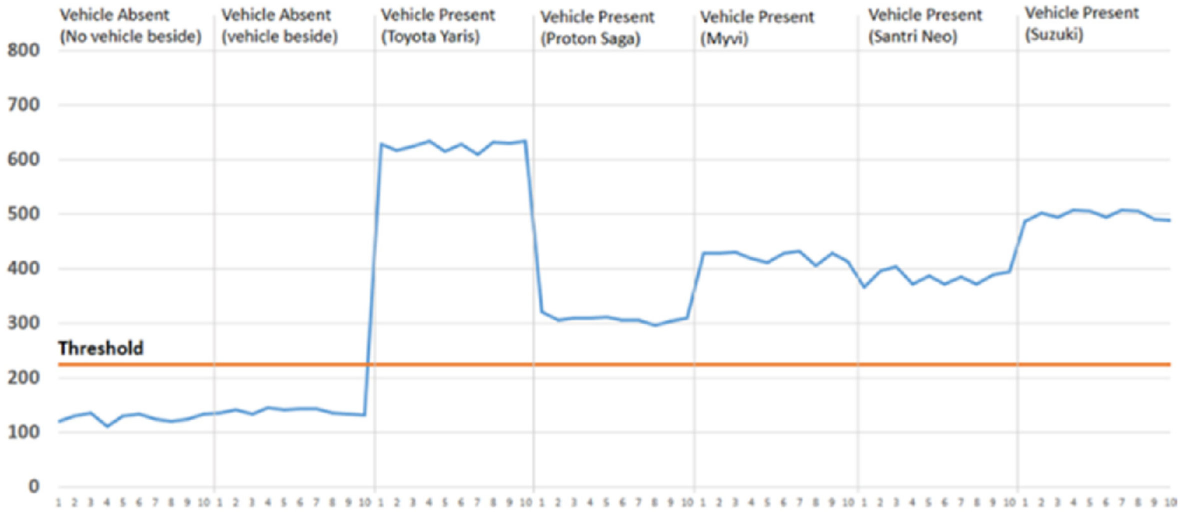


Fig. 13. Variation of magnetic strength readings with vehicle presence.

5. Experimental results

The effectiveness of our system was put to the test in an array of meticulously designed scenarios, yielding a multitude of intriguing results. In this section, we delve into the findings and outcomes extracted from these varied system experiments. The evaluation phase encompasses three distinct cases that collectively assess the system's robustness and versatility. The initial case examines the system's ability to instantaneously update information regarding parking spot availability, testing its aptitude for real-time updates. The second case investigates the dependability of the LoRa communication interface, ensuring its trustworthiness under various circumstances. Finally, we gauge the system's sustainability, affirming its potential for long-term operation. By delving into these experimental results, we hope to offer comprehensive insight into the system's performance and potential.

5.1. System validation

This experiment primarily focuses on validating the accuracy of the data collected by the developed system. As depicted in Fig. 15, the smart parking node is situated at the centre of the parking lot, ready to detect and report on both vacant and occupied parking statuses. The data gathered by the sensors is subsequently updated to the Internet via the LoRaWAN gateway, making it accessible through both the TTN server

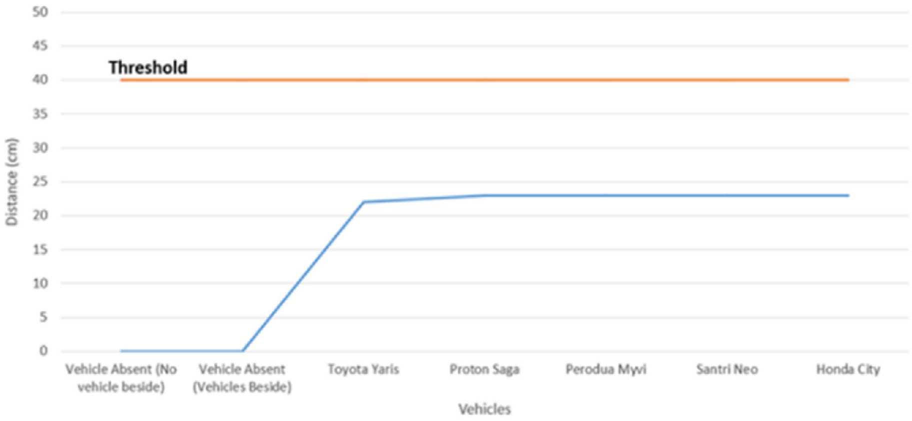


Fig. 14. Variation of ultrasonic distance readings with vehicle presence.

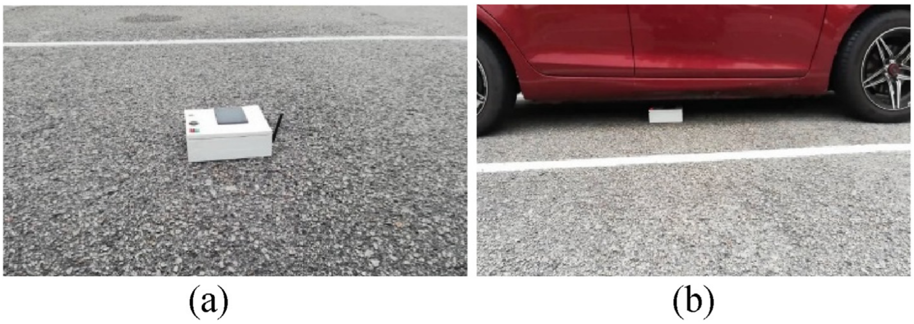


Fig. 15. System validation: (a) Vacant, (b) Occupied.

and ATT Glance. The ATT Maker is in sync with the TTN server, ensuring a seamless data synchronization process during the software development phase. This process necessitates the input of target TTN server information, including device EUI, application ID, device address, network session key, and application session key.

The values procured by the sensor are presented in an easily digestible format, thanks to the rules established within the ATT Maker that govern the assets (actuators). This amalgamated information can then be conveniently accessed and viewed on mobile devices. Fig. 16 (a) depicts the user interface of ATT Maker during a scenario where the parking lot is vacant. A vacant parking status is indicated when the waterproof ultrasonic sensor detects distances exceeding 40 cm, and the magnetometer registers magnetic strengths of less than 225 T. During such instances, the smart parking node's green LED indicator is consistently illuminated. The sensor's reading is displayed as a dash on the interface, signifying that the detected distance is beyond its maximum range of 40 cm.

Conversely, when the sensor detects a vehicle within its range, the system's actuator, represented by a red LED, illuminates, indicating that the parking space is occupied. The developed sensing unit includes both a physical and a virtual LED that mirrors each other's status. Fig. 16(b) presents the ATT Maker interface displaying an 'occupied' parking status, alongside the corresponding red LED light. Additionally, as shown in Fig. 17, the system sends an instant notification to the user's mobile device, alerting them about the current parking status. Any detected change in the parking status prompts ATT Maker to execute programmed rules, which then trigger these notifications to the driver's mobile application or ATT Glance displayed on their mobile phone.

5.2. LoRa/LoRaWAN connectivity analysis

Our research includes a comprehensive evaluation of the connectivity and reliability of data transmission between the sensing nodes and the LoRaWAN gateway. We performed this test under various conditions, which included different times of day and inclement weather scenarios, to assess the robustness of our system. In this particular scenario, we positioned a single sensing node at three distinct locations, each separated by a 10 m distance and approximately 1 km away from the LoRaWAN gateway (refer to Fig. 18). This setup was designed to mimic the behaviour of sensing nodes situated at varied spots within the same parking area.

The evaluation spanned over 6 h and was conducted under a range of conditions including strong winds and light rain, during both daylight and night hours. Every 10 min, we measured the Received Signal Strength Indication (RSSI) and the Signal-to-Noise Ratio (SNR) to assess the quality of the transmitted signal based on the distance from the gateway.

We calculated the Time on Air (ToA), which refers to the duration taken for the gateway to receive the packet sent by the sensing node, based on the LoRa duty cycle. The duty cycle— the period during which a system is active or operating— is expressed as a percentage, equating to 1% for LoRa.

Our results showed that the signal maintained a consistent 5-s interval or dwell time for transmitting a new signal at a frequency with a ToA of 50.5 ms. This remained constant throughout the experiment despite frequency changes, with the frequency range lying between 922 and 923 MHz.

In terms of signal strength, the device recorded 71.75 dB of free space losses. Path loss, or the energy lost as it traverses the distance from transmitter to receiver, decreases with increased distance in a LoRaWAN network. This reduction is influenced by several factors such as wave reflections and refractions from objects.

To achieve optimum radio signal efficiency, the gateway's antenna needs to be positioned outdoors at an elevated height, minimizing obstacles within the Fresnel zone. The configuration of antennas for both the gateway and the end nodes must be customized according to their geographical frequency.

(a) Vacant

(b) Occupied

Fig. 16. GUI of ATT Maker for parking lot.

During the 6-h connectivity evaluation, we ensured the optimal positioning of the antenna, oriented upwards and with minimal interference in the direct sightline between the transmitter (Tx) and receiver (Rx). It is important to note that any obstacles within the first Fresnel zone can negatively impact the received signal strength and the connectivity range.

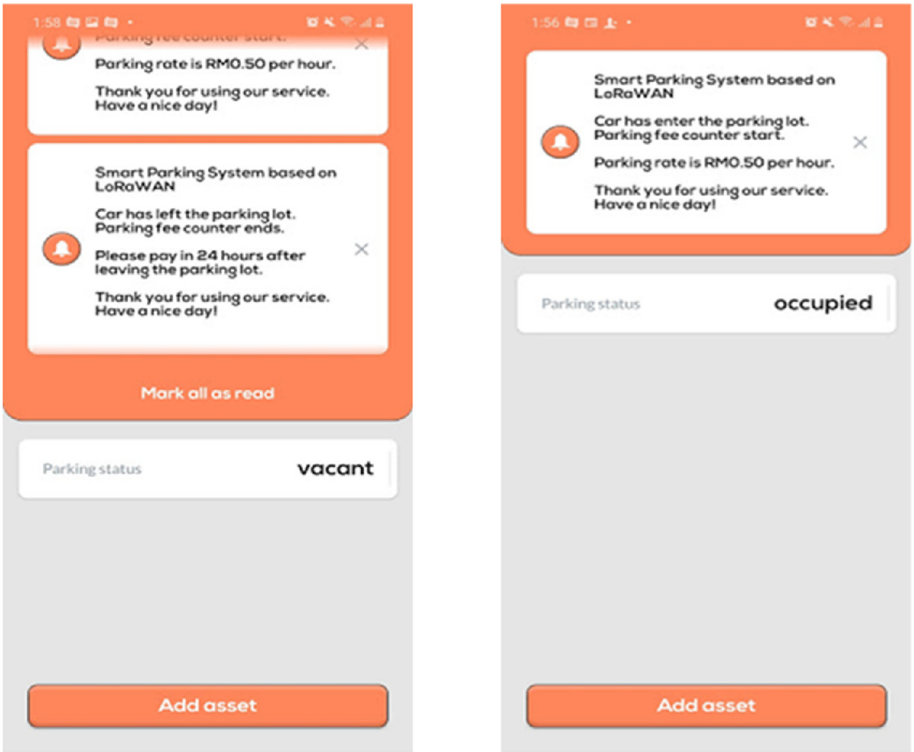
Our system demonstrated robust performance, with the battery reliably powering the device for the entire duration of the 6-h test. We calculated the path losses for each of the three node locations, recording losses of 51.75 dB, 57.77 dB, and 61.29 dB respectively. These calculations factored in the distance from the gateway to each location, considering an average frequency of 922.5 MHz. Our findings confirm that the signal loss increases as the node's distance from the gateway expands, underscoring the importance of proximity for maintaining strong connectivity in our system.

Our experimental campaign, which took place at three distinct locations with a 10-m gap between each, has yielded some enlightening data. The RSSI and SNR values were documented over 6 h, during which our system was tested under night-time conditions with the battery at full capacity, demonstrating its sustainability.

Fig. 19 provides a graphical depiction of the RSSI and SNR data collected from 19:00 to 01:00. In this 6-h window, the timeline from 19:00 to 21:00 is representative of data from location 1 (10 m), 21:00 to 23:00 corresponds to location 2 (20 m), and 23:00 to 1:00 pertains to location 3 (30 m). The graph illustrates a clear trend: as the distance increases, the RSSI values show a gradual decline. This trend is indicative of a slight loss in signal strength with increasing distance from the gateway. However, it's crucial to note that despite this decrease, the signal strength remains well within acceptable limits for our application, ensuring reliable data transmission.

The SNR values present another aspect of the system's performance. Despite slight variations, the SNR remains relatively consistent across all three locations. This consistency indicates that our system maintains a good quality signal, irrespective of the distance from the gateway. Moreover, the magnetometer data shows that despite the changes in distance and accompanying RSSI and SNR values, it is not affected by signal variations. Its readings consistently remain below the threshold of 225 T, which validates that there is no vehicle presence in the parking lot across all the tested locations. We verified the accuracy of our results by cross-referencing the data from the Arduino IDE's serial port, the TTN server, and the AllThingsTalk Maker interface. This step ensures the reliability of our data before presenting it in Fig. 19.

The overall analysis of these data points demonstrates a systematic correlation between distance and RSSI values and the reliable



Parking fee counter start.
Parking rate is RM0.50 per hour.
Thank you for using our service.
Have a nice day!

Smart Parking System based on LoRaWAN
Car has left the parking lot.
Parking fee counter ends.
Please pay in 24 hours after leaving the parking lot.
Thank you for using our service.
Have a nice day!

Parking status vacant

Smart Parking System based on LoRaWAN
Car has enter the parking lot.
Parking fee counter start.
Parking rate is RM0.50 per hour.
Thank you for using our service.
Have a nice day!

Parking status occupied

Fig. 17. Parking status notification via smartphone ATTM GUI.

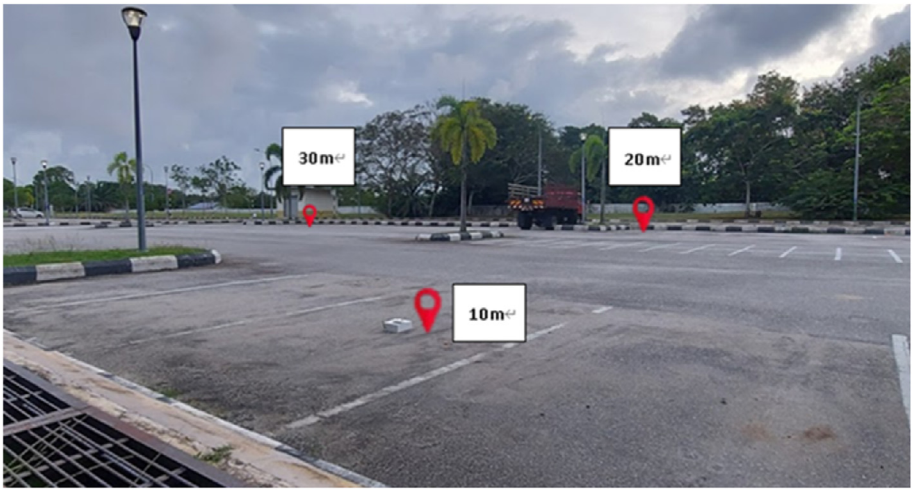


Fig. 18. Parking Layout of nodes location for connectivity testing.

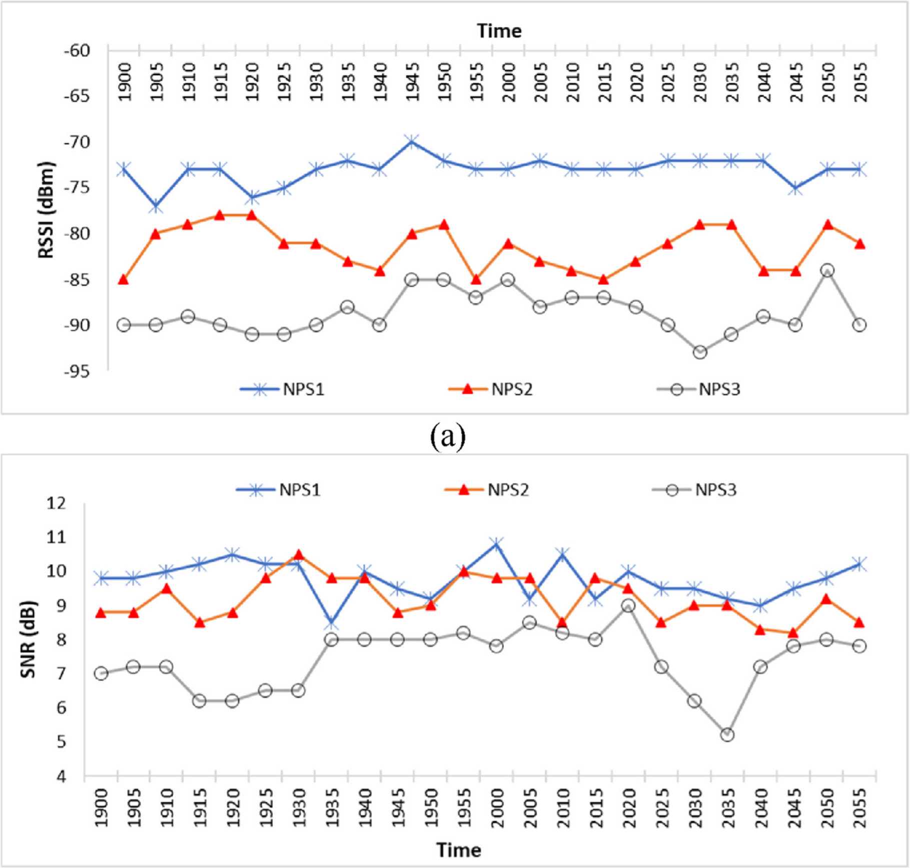
performance of the magnetometer across varying signal strengths. The detailed discussion of these results, as per Fig. 19, provides a deeper understanding of the system's performance and reliability, substantiating our claim of an effective IoT-enabled Smart Parking Management System.

Regardless of weather conditions, our system demonstrated consistent signal transmission throughout the experiment. It proved to be resilient to changes in environmental factors, showcasing its potential to perform under various weather scenarios. This resilience is essential for its real-world deployment in outdoor parking areas, where it may encounter a variety of weather conditions. While our current study did not include testing under extreme weather conditions like heavy snow or torrential rain, the robustness of our system under mild weather conditions suggests that it is likely to perform well in harsher environments. However, we recognize the importance of this concern and will extend our testing to include such conditions in our future work to further validate the reliability of our system.

5.3. LoRa SNR and RSSI analysis

This experiment scrutinizes the effects of parking status and gateway proximity on received signal strength indication (RSSI), Signal-to-Noise ratio (SNR), and sensors readings. We ran a series of measurements where a vehicle was intermittently parked in the parking lot, and the corresponding RSSI, SNR, and sensor data were logged and analyzed. Importantly, the test proceeded without any interruption between 8:00 a.m. and 2:00 p.m. on a clear day at the university campus, which allowed for direct solar panel operation.

RSSI was used to evaluate the LoRaWAN gateway's performance in



(a)

(b)

Fig. 19. Nodes-Gateway connection quality with time (a) RSSI, (b) SNR for varying locations.

receiving signals from the sensors. Meanwhile, SNR measurements provided insight into the ratio between the received power signal and the background noise level. With a lower boundary of -120 dBm, a smaller RSSI value indicates a weaker signal, whereas values closer to -30 dBm signify a stronger signal. SNR is typically within the range of -20 to 20 dB, with values closer to 10 dB denoting less signal corruption. Data for RSSI, SNR, and sensor values were recorded at 10-min intervals. Table 1 details the sensor node's registered readings on the TTN server and ATT Maker, with a timeline graph displaying parking status: green shading indicates an empty parking lot, while red represents an occupied lot.

Initially, we left the parking lot vacant for an hour to assess the deployed sensors' signal and LoRaWAN connectivity, yielding an average RSSI of -79.3 dBm. From 9:00 a.m. to 11:50 a.m., a parked vehicle caused the RSSI to drop to an average of -92.78 dBm. Once the vehicle departed, the signal strength increased to an average of -86.67 dBm over the next 30 min. This pattern persisted throughout the testing period, confirming that vehicles in the parking lot weakened the RSSI of LoRaWAN. However, interestingly, the sensor readings remained largely unaffected by the signal fluctuations, with the device continuing to accurately transmit data.

Our SNR analysis also revealed a stable average of approximately 9 dB during the initial hour when the parking lot was vacant. The arrival of a vehicle between 9:00 a.m. and 11:50 a.m. caused a notable drop in SNR values to an average of 4.75 dB. However, the SNR rebounded to an average of 8.8 dB over the next 30-min period when the parking lot was vacated.

Finally, the waterproof ultrasonic sensor provided key readings for these different conditions. When the parking lot was unoccupied, the sensor registered 0 cm, indicating no vehicle was detected within its 40 cm range. Upon a car's arrival, the sensor detected its presence at a distance of 23 cm. Additionally, the magnetometer readings clearly varied depending on whether the parking lot was empty or occupied. Throughout the experiment, both the ultrasonic sensor and the magnetometer provided stable readings, successfully validating the proposed system.

6. Conclusions and future work

An innovative SPS based on LoRa/LoRaWAN communication technology has been designed and fabricated to cater to the high demand for smart parking that has been growing simultaneously with the number of parking lots that take up a wide area. Owing to their accuracy and compatibility, the three-axis magnetic sensor and ultrasonic sensor have been utilized for detecting parking lot occupancy. In addition, LoRa/LoRaWAN communication technology was chosen in the proposed IoT-SPMS-LoRaWAN system because of its independent infrastructure, license-free frequency bands, low power consumption, and long-range coverage. The collected data are transmitted in real time from the smart sensing node using a LoRa shield to the TTN IoT server through a LoRaWAN gateway. Parking status information can be monitored in real time via the ATTM IoT GUI using smartphones and other Internet-connected devices. The smart sensing node is powered using a rechargeable battery that is attached to a solar panel to charge the battery through a solar charger shield when no vehicle is located above the sensor, thereby maintaining a continuous operation of nodes. The proposed system has been deployed and validated in a real parking lot as a single node with a single gateway and has performed effectively. Various parameters have been considered to evaluate the system performance, including distance to the gateway and parking occupancy status. Several performance metrics related to the LoRa signal have been evaluated, such

Table 1
Sensing Unit Collected Data from attm

Time/Parkin Status	RSSI	SNR	Magnetometer	Ultrasonic Sensor
0800	-76	9	112	0
0810	-82	8.8	100	0
0820	-79	9.5	100	0
0830	-79	9.8	95	0
0840	-81	8.8	107	0
0850	-79	8.2	105	0
0900	-93	2.8	382	23
0910	-91	4.8	392	23
0920	-91	5.5	373	23
0930	-89	7	392	23
0940	-87	8.2	387	23
0950	-91	6.8	377	23
1000	-95	5	387	23
1010	-95	4.5	385	23
1020	-93	6	387	23
1030	-93	6.2	392	23
1040	-93	5.5	380	23
1050	-94	5	392	23
1100	-94	6.2	390	23
1110	-94	6.8	407	23
1120	-95	5	395	23
1130	-95	4.5	392	23
1140	-94	6.2	380	23
1150	-93	6.2	392	23
1200	-85	8.8	161	0
1210	-85	9.8	132	0
1220	-90	7.8	148	0
1230	-75	9.5	324	23
1240	-74	10.20	326	23
1250	-73	9.2	337	22
0100	-72	8.5	340	22
0110	-76	9.2	326	22
0120	-73	9.2	335	22
0130	-43	10	129	0
0140	-43	10.2	126	0
0150	-45	9.5	134	0
0200	-49	10	131	0

as SNR and RSSI. Implementing the IoT-SPMS-LoRaWAN system in the entire parking areas of smart cities, particularly in crowded areas, will help reduce traffic congestion, improve life quality, and result in a cleaner environment. Our system can be extended to collect data on the duration of the car parked for bill calculation and automatic bill payment for e-money application users and any online banking pre-linked to the application. In future studies, we will implement multiple sensing nodes in a multi-parking space to evaluate the network scalability and further evaluate the LoRa network performance. We also plan to conduct tests under various weather conditions such as snow and rain to ensure the system's robustness. Changing our current non-switch type magnetometer to a switch type could enhance our capacity to track parking durations by providing distinct indications of active and passive system modes. This would make data translation and subsequent calculations easier. Ultimately, our goal is to design a compact, water-resistant iteration with a higher infill rate to withstand adverse conditions like flooding and high pressure.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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