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Smart Underground Parking with Flood Detector

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Abstract:

This paper presents the development of a smart underground parking system integrated with flood detection using infrared and water level sensors. The system utilizes Arduino and ESP8266 modules for data processing and IoT-based data transmission. Testing involved basic performance assessments to evaluate the accuracy of vehicle detection and flood monitoring. The vehicle detection system achieved an 80% accuracy rate using infrared sensors, while the flood detection system effectively tracked water levels. These features enable timely responses to potential flooding and parking issues, helping to minimize damage and improve safety. Real-time monitoring and alert notifications are provided through the Blynk application, enhancing user awareness and system responsiveness.

Keywords: Smart parking, flood detection, IoT, ESP8266, Blynk.

Introduction

In today's digital era, the Internet of Things (IoT) has simplified daily tasks by connecting devices intelligently, improving efficiency and promoting automation across various fields. Urban underground spaces such as parking garages, while space-efficient, are increasingly vulnerable to flash floods, necessitating resilient smart solutions. As highlighted by (He et al., 2024), underground facilities are highly susceptible to water intrusion, particularly during heavy rainfall, making early warning systems critical in these environments.

A primary application of IoT is in smart parking management, where technologies like infrared (IR) sensors and Optical Character Recognition (OCR) reduce search times and enhance parking management accuracy by detecting vehicle presence and automatically recognizing license plates (Joshi et al., 2023; Elfaki et al., 2023). Mobile applications, such as Blynk, and long-range communication technologies like LoRaWAN, allow users real-time access to parking information on their smartphones, which helps to alleviate congestion in urban centers (Angare et al., 2021; Jabbar et al., 2024). These smart parking solutions are particularly useful in densely populated cities like Barcelona and Busan, where wireless sensor-based systems have optimized traffic flow and space utilization (Biyik et al., 2021).

Beyond parking, IoT has also been applied in real-time monitoring and control of public infrastructure. For instance, Abdul Rahman et al. (2024) demonstrated the effective use of Blynk in managing solar-powered street lighting systems, highlighting its potential in broader smart city applications.

Another critical challenge in urban areas is flash flooding, which poses a risk to parked vehicles. IoT-enabled flood detection systems using ultrasonic sensors warn vehicle owners about rising water levels in parking areas. In rural settings, GSM technology offers an alternative by delivering flood alerts through SMS, though it faces challenges with network coverage (Hasbullah et al., 2020; Hassan et al., 2020)

Integrating smart parking with flood detection systems can mitigate flood-related vehicle damage. For instance, combining ultrasonic sensors and IoT enables the simultaneous monitoring of parking availability and water levels, as demonstrated in studies that show reduced vehicle damage through real-time alerts (Naik, 2020; Flora A et al., 2019). This integration could be particularly beneficial for flood-prone cities, helping prevent property damage and improving parking efficiency.

This study aims to develop an integrated system that combines smart parking management with flood detection, offering real-time alerts on both parking availability and flood risks. The study also assesses the system's reliability in low-network conditions and its scalability in larger, more complex parking environments.

Literature Review

The integration of the Internet of Things (IoT) in urban infrastructure has proven effective in tackling two major challenges: parking congestion and flood damage. In smart parking management, infrared (IR) sensors and mobile applications like Blynk deliver real-time updates that significantly shorten the time drivers spend searching for spaces and ease traffic buildup in parking areas (Vignesh N. et al., 2024; Angare et al., 2021; Elfaki et al., 2023). Additionally, Optical Character Recognition (OCR) technology improves the accuracy of license-plate detection, though motion-based processing delays still pose challenges. Veeramanickam et al. (2022) demonstrated that First-Come-First-Serve (FCFS) scheduling on Arduino can optimize space usage and minimize parking delays. Best practices in cities such as Barcelona and Busan further showcase the success of wireless sensor systems in optimizing traffic flow and space utilization (Biyik et al., 2021; Fahim et al., 2021), while deep-learning models like YOLO and ResNet can boost detection accuracy up to 98.7%, even when facing occlusion and heavy computational demands (Li et al., 2023).

At the same time, IoT-based flood detection systems play a crucial role in strengthening urban resilience.

Ultrasonic sensors paired with IoT platforms have proven effective at monitoring water levels and providing early warnings in flood-prone areas (Hasbullah et al., 2020; Binti Zahir et al., 2019). In rural contexts, GSM-based systems send alert notifications via SMS, although network coverage limitations can hinder their reach (Hassan et al., 2020). Jang & Jung (2023) introduced industrial radar for more precise water-flow monitoring in underground parking garages, further enhancing the reliability of flood warnings.

Recent research emphasizes the advantage of integrating smart parking management with flood detection to create a more comprehensive solution. Jabbar et al. (2024) and Naik (2020) demonstrated how combining IoT, LoRaWAN, and ultrasonic sensors enables simultaneous monitoring of parking availability and water levels, delivering real-time alerts that help prevent vehicle damage. Hamzah et al. (2024) also reported significant reductions in flood-related vehicle damage and enhanced safety through synchronized updates on parking status and water levels (Flora A. et al., 2019). Such integration is expected to improve parking management efficiency while bolstering flood mitigation efforts in urban environments.

Research Methodology

This study began with a literature review to identify gaps in existing smart parking and flood detection solutions and to inform system requirements. Functional requirements included vehicle detection, flood alerting, and entrance gate control. Nonfunctional requirements emphasized reliability and operational efficiency.

System design comprised an infrared IR sensor for vehicle detection, an ultrasonic water level sensor for flood monitoring, an Arduino UNO microcontroller for data processing and display control, and an ESP8266 module for data transmission to the Blynk smartphone application. The IR sensor triggers the Arduino UNO to drive a servo motor that opens or closes the gate and updates a 16 by 2 LCD display with current parking availability. The water level sensor continuously measures sub floor water depth. When depth exceeds a caution threshold of 5.1 centimetres or a danger threshold of 7 centimetres an immediate alert is sent via the Blynk application and the entrance gate is locked to prevent entry into flooded areas (Hassan et al., 2020).

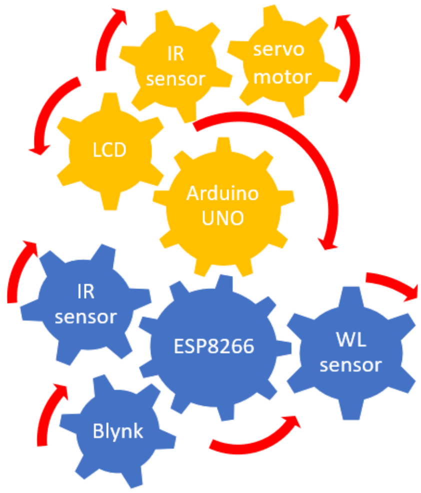

Figure 1. Block Diagram of the Smart Underground Parking System with Flood Detector

An operational flow chart guides system behaviour. Upon detection of a vehicle the system checks for available spaces updates the display and then enters flood monitoring mode. If water depth surpasses threshold values the LCD display and the Blynk application both show warning messages and gate control overrides parking access.

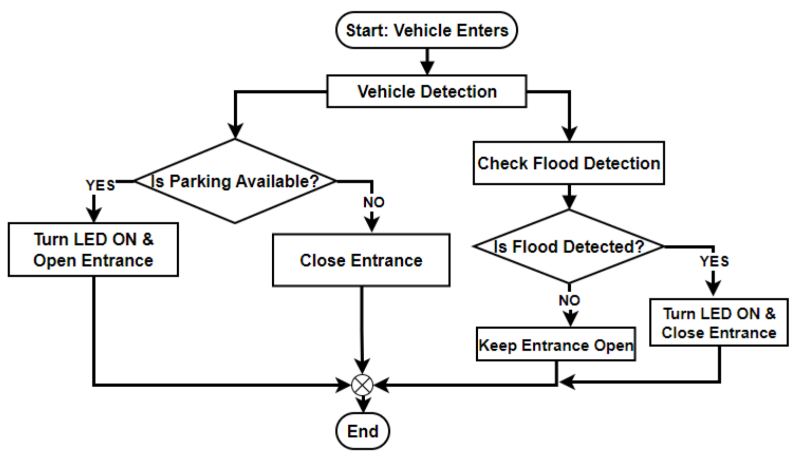

Figure 2: Flowchart of the Smart Underground Parking System with Flood Detector

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Component selection focused on the Arduino UNO for its extensive community support and compatibility with sensors while the ESP8266 module provided Wi Fi connectivity for uninterrupted data transmission. Digital pins on the Arduino UNO interface with the IR sensors the servo motor connects to a pulse width modulation pin for gate actuation and the 16 by 2 LCD connects via parallel data lines. A 7805-voltage regulator converts a 12-volt supply to a stable 5-volt output to protect sensitive components.

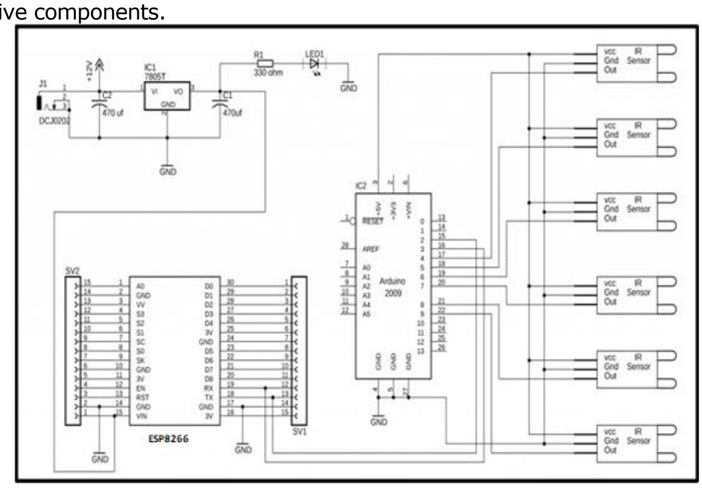

Figure 3: Wiring Diagram of Smart Parking System using Arduino UNO and ESP8266

Software development employed the Arduino IDE and C ++ programming language. Custom libraries handled sensor data acquisition servo control and communication with the Blynk application. A user interface in the Blynk application displayed slot availability water level readings and alert notifications and allowed remote gate operation.

Individual bench tests were performed on the IR sensor the water level sensor the servo motor and the LCD display to verify correct operation. System integration testing followed. Flood scenarios were simulated by varying water depth in a controlled container and the system response was measured across ten trials to evaluate detection accuracy response latency and reliability. Results demonstrated consistent updates and fail-safe operation under a range of conditions confirming suitability for underground parking environments.

Discussion of analysis and findings

The series of tests carried out on the Smart Underground Parking System with Flood Detection reveal its dual strengths in managing vehicle entry and guarding against flood hazards. From the moment a vehicle is sensed, the system updates parking availability in real time, controls the entry barrier, and then seamlessly transitions into flood-monitoring mode—ensuring that no one enters when water levels rise above safe limits.

During the parking space monitoring trials, the infrared sensors detected vehicles accurately in eight out of ten attempts, yielding a detection accuracy of approximately; (Baratloo et al., 2015)

$$Flood\ Detection\ Accuracy = \frac{Correct\ Detections}{Total\ Relevant\ Trails} x\ 100 = \frac{2}{2}\ x\ 100\ \approx 100\%$$

When no vehicle was present (Trials 3 and 6), the system wisely held its previous status, avoiding unnecessary gate movements or status updates. The LED indicators mirrored this performance by lighting up only when slots were genuinely available, and the servo-driven barrier consistently opened or closed in harmony with slot availability.

Table 1: Parking Space Monitoring Test Results

Trail	Vehicle Detection (IR Proximity)	Parking Space Available	LED Status	Parking Status (Blynk)	Slot 1 Status	Slot 2 Status	Slot 3 Status	Slot 4 Status	Servo Motor	Barrier Status
1	Yes	No	OFF	Full	Full	Full	Full	Full	OFF	Closed
2	Yes	Yes	ON	Avail	Full	Full	Full	Avail	ON	Open
3	No	-	OFF	-	Avail	Avail	Avail	Avail	ON	Open
4	Yes	No	OFF	Full	Full	Full	Full	Full	OFF	Closed
5	Yes	Yes	ON	Avail	Full	Full	Full	Avail	ON	Open
6	No	-	OFF	-	Avail	Avail	Avail	Avail	ON	Open
7	Yes	No	OFF	Full	Full	Full	Full	Full	OFF	Closed
8	Yes	Yes	ON	Avail	Full	Full	Full	Avail	ON	Open
9	Yes	Yes	ON	Avail	Full	Full	Full	Avail	ON	Open
10	Yes	No	OFF	Full	Full	Full	Full	Full	OFF	Closed

Avail = Available

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Flood monitoring proved just as dependable. Out of two trials that deliberately raised water levels above the danger threshold, both were detected correctly—achieving a perfect 100% in flood detection accuracy: (Baratloo et al., 2015).

$$Parking\ Detection\ Accuracy = \frac{Correct\ Detections}{Total\ Trails} x\ 100 = \frac{8}{10}\ x\ 100\ \approx 80\%$$

In these high-water tests, the system's response times were measured at 3 seconds (Trial 3) and 4 seconds (Trial 6), averaging 3.5 seconds from detection to gate closure. (Addad et al., 2010):

$$D_r(l) = \theta_8(l) - \theta_e(l)$$

In Trial 3, the barrier closed 3 seconds after flood detection $D_r = 3$ seconds, and in Trial 6, it closed 4 seconds after flood detection $D_r = 4$ seconds.

$$Average\ Response\ Time = \frac{\sum Respond\ Times}{Number\ of\ trails} = \frac{3+2}{2} = 3.5\ seconds$$

The system's failure rate was assessed based on the detection reliability for both parking and flood conditions. The failure rate λ is calculated using the following formula (Addad et al., 2010). Therefore, the failure rate is calculated using the following formula

$$\lambda = \frac{k}{nt} = \frac{0}{10 \times 1}\ x\ 100\% = 0\%$$

where k is the number of failures, n the number of trials, and t the assumed one-year observation period.

Table 2: Flood Monitoring Test Results

Trail	Water Level (cm)	Flood Detected	Flood LED Status	Blynk Status	Servo Motor	Barrier Status	Response Time (seconds)
1	Normal	No	OFF	Normal	ON	Open	-
2	Normal	No	OFF	Normal	ON	Open	-
3	High	Yes	ON	Flood	OFF	Closed	≈3
4	Normal	No	OFF	Normal	ON	Open	-
5	Normal	No	OFF	Normal	ON	Open	-
6	High	Yes	ON	Flood	OFF	Closed	≈4
7	Normal	No	OFF	Normal	ON	Open	-
8	Normal	No	OFF	Normal	ON	Open	-
9	Normal	No	OFF	Normal	ON	Open	-
10	Normal	No	OFF	Normal	ON	Open	-

The Blynk application faithfully reflected these real-world outcomes. In Trials 2 and 8, it displayed "Available" alongside an open gate; in Trial 3, it immediately switched to "Flood" and closed the barrier—exactly matching sensor data and barrier actions.

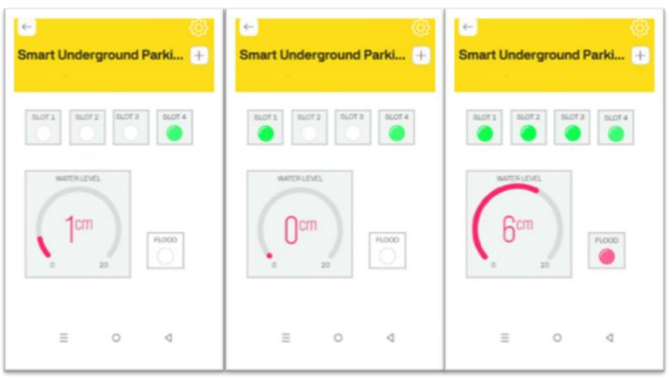

Figure 4; Blynk results for trials 2, 8, and 3.

Finally, the hardware layout (Figures 5 and 6) brings all components into a cohesive whole: IR proximity sensors, ultrasonic water-level sensor, status LEDs, Arduino UNO, ESP8266 module, servo motor, and LCD display work in concert to deliver a user-friendly yet robust solution for underground parking in flood-prone settings.

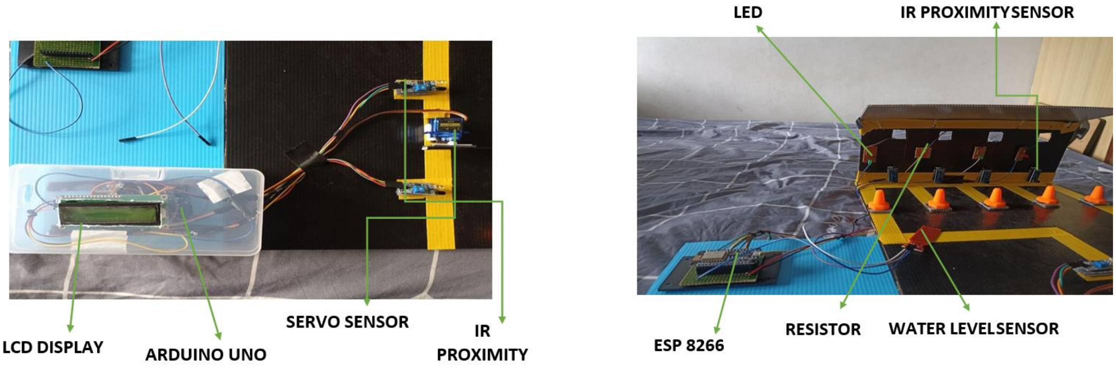

Figure 5 and 6: Hardware Components and Layout of the Smart Underground Parking with Flood Detection System

In summary, the Smart Underground Parking with Flood Detector system performed reliably, achieving an 80% accuracy in parking detection and 100% accuracy in flood detection. The average response time for flood detection was 3.5 seconds, with a 0% failure rate across all tests. Overall, the system effectively managed parking and flood conditions, providing real-time updates through the Blynk app and maintaining high reliability in all test scenarios.

Discussion of analysis and findings

Based on the results obtained from 10 trials, it can be concluded that the Smart Underground Parking with Flood Detector system effectively enhances parking management efficiency while providing significant protection against flood risks. Achieving 80% accuracy in vehicle detection and 100% accuracy in flood detection, with an average response time of 3.5 seconds, the system ensures real-time monitoring and timely preventive actions. However, the limited number of trials indicates that further extensive testing is necessary to validate these findings across more diverse and real-world scenarios. The system’s implementation of IoT technology integrated with the Blynk application offers convenient remote management of parking and flood alerts, making it a reliable and scalable solution for underground parking environments. Nonetheless, its reliance on stable internet connectivity means poor or intermittent network coverage may delay or disrupt real-time updates and alerts, potentially impacting system effectiveness in critical situations. Recommendations for future work include increasing the number and diversity of test trials to improve the robustness and generalizability of the system's performance data; developing fallback mechanisms to maintain functionality during internet outages or weak network conditions, such as local alarms or offline data caching; integrating additional sensor technologies and employing machine learning algorithms to enhance detection accuracy and predictive capabilities; and conducting field testing in real underground parking facilities to evaluate system performance under real environmental and operational conditions.

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