Afro-Asian Journal of Scientific Research (AAJSR)
المجلة الأفروآسيوية للبحث العلمي
E-ISSN: 2959-6505
Volume 4, Issue 3, 2026
Page No: 126-133
Website: https://aajsr.com/index.php/aajsr/index
SJIFactor 2024: 5.028 ISI 2025: 0.915 معامل التأثير العربي (AIF) 2025: 0.76

Enhancing Smart Parking Systems Using an IoT-Based ESP8266 in Smart Cities

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تطوير أنظمة مواقف السيارات الذكية باستخدام تقنية إنترنت الأشياء ووحدة *ESP8266* في المدن الذكية

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Received: May 15, 2026	Accepted: July 23, 2026	Published: August 09, 2026

Abstract:
Rising urbanism in smart cities increases the need for clever and efficient parking solutions in these areas. This work aims to build from the ESP8266 microcontroller a smart parking system based on the Internet of Things with maximum efficiency. Built-in Wi-Fi, low power consumption, and economy of cost make the ESP8266 a better choice than microcontrollers like Arduino and single-board computers like Raspberry Pi. Although Arduino requires other modules for wireless connections, direct internet access on the ESP8266 enables real-time data flow. Furthermore, as its architecture is simpler than that of the Raspberry Pi and consumes less power, the ESP8266 is ideal for uses sensitive to cost and energy. The suggested approach reduces traffic by monitoring and controlling parking availability using the wireless networking capability of the ESP8266; therefore, it optimizes space use. Faster response times, cheaper installation costs, and reliable performance at a lower power consumption, testing and analysis show that the ESP8266-based solution provides. These results reveal that the ESP8266 is a flexible and versatile choice for developing Internet of Things-enabled smart parking systems.

Keywords: Smart Parking Systems, Smart Cities, ESP8266.

الملخص:
يؤدي التوسع الحضري المتزايد في المدن الذكية إلى زيادة الحاجة إلى حلول ذكية وفعّالة لمواقف السيارات. يهدف هذا العمل إلى تطوير نظام ذكي لمواقف السيارات يعتمد على إنترنت الأشياء باستخدام المتحكم الدقيق ESP8266، مع تحقيق أعلى قدر ممكن من الكفاءة. ويُعد ESP8266 خيارًا مناسبًا مقارنةً بمتحكمات دقيقة مثل Arduino وأجهزة الحاسوب أحادية اللوحة مثل Raspberry Pi، وذلك بفضل احتوائه على شبكة Wi-Fi مدمجة، وانخفاض استهلاكه للطاقة، وانخفاض تكلفته. ففي حين يتطلب Arduino وحدات إضافية للاتصال اللاسلكي، يتيح ESP8266 الاتصال المباشر بالإنترنت، مما يدعم نقل البيانات في الوقت الفعلي. كما أن بنيته الأبسط مقارنةً بـ Raspberry Pi واستهلاكه المنخفض للطاقة يجعلان منه خيارًا مثاليًا للتطبيقات التي تراعي التكلفة وكفاءة الطاقة. يسهم النظام المقترح في تقليل الازدحام المروري من خلال مراقبة مدى توفر مواقف السيارات وإدارتها باستخدام إمكانات الاتصال اللاسلكي التي يوفرها ESP8266، مما يساعد على تحسين استغلال المساحات المتاحة. وأظهرت نتائج الاختبارات والتحليل أن الحل القائم

على ESP8266 يوفر سرعة استجابة أعلى، وتكاليف تركيب أقل، وأداءً موثوقًا مع انخفاض استهلاك الطاقة. وتوضح هذه النتائج أن ESP8266 يمثل خيارًا مرنًا ومتعدد الاستخدامات لتطوير أنظمة مواقف السيارات الذكية المعتمدة على إنترنت الأشياء.

الكلمات المفتاحية: أنظمة مواقف السيارات الذكية، المدن الذكية، ESP8266، إنترنت الأشياء.

INTRODUCTION:

The great rise in automobile ownership brought about by urbanization presents parking management problems. Comprising automated equipment and strongly integrated with the Internet of Things (IoT), the smart parking system is [1]. Manual monitoring under traditional methods causes congestion, fuel waste, and driver annoyance. Studies reveal that a large portion of metropolitan traffic comes from drivers looking for parking. By means of real-time monitoring and IoT-based automation, smart parking solutions seek to maximize space use, hence lowering inefficiencies and environmental impact [2].

Though many of the technologies, RFID, sensor networks, cloud-based platforms, that have been investigated are expensive and complicated. Because IoT integration may connect devices, automate data collecting, and increase system efficiency, it has attracted interest. The Internet of Things (IoT) has completely changed habitual human behavior over the past several years by offering many facilities and comfort choices so that daily living runs easily [3].

Affordability and scalability in smart parking systems depend on choosing the correct microcontroller.

Smart parking's perfect microcontroller must strike a mix between cost, power economy, connection, and processing capacity. Popular in IoT projects, Arduino, Raspberry Pi, and ESP8266 each have unique benefits. Although Arduino is easy to programmed, it lacks built-in Wi-Fi, so extra modules that add expense and complexity are needed. Less useful for battery-powered parking systems, the Raspberry Pi is strong but uses more energy and calls for greater hardware. On comparison, the ESP8266 is a better option for real-time parking monitoring and wireless communication since it provides integrated Wi-Fi, a small size, and low battery consumption.

Smart cities must consist of information and communication technology (ICT) as well as the Internet of Things (IoT), which would enable citizens to lead sustainable lives and aid in increasing operational efficiency and services [4]. The built-in Wi-Fi of the ESP8266 allows direct internet connection, therefore removing the requirement for other modules needed by Arduino. It is also perfect for low-energy smart parking installations since it uses noticeably less power than Raspberry Pi. Innovative technologies are driven by their movement towards the power system structure's efficiency [5]. Its small physical factor makes integration into small-sized sensor-based monitoring systems simple. Furthermore, the ESP8266's low cost helps maintain scalability and efficiency while generally lowering system expenses. These benefits make it a sensible and reasonably priced fix for IoT-based smart parking.

Real-time monitoring of parking spaces is a main purpose of smart parking systems. Manual checks used in conventional parking systems cause inefficiency. The ESP8266 constantly gathers data from sensors and sends it via a wireless network, hence improving automation [6,7]. Its Wi-Fi module lets consumers verify space availability via mobile apps or cloud systems by means of quick updates. An ESP8266-based system offers accurate and automatic updates, thus optimizing space use, unlike conventional approaches that call for regular human interaction.

Due to their reliance on pricey hardware and high-power consumption, many current systems remain costly, energy-intensive, and ineffective even with improvements in smart parking solutions in this study. While Raspberry Pi consumes more power and is inappropriate for battery-operated devices, Arduino-based solutions need extra Wi-Fi modules, which raises expenses for applications. One of the most significant indicators of civilization is the advancement of efficient transportation vehicles. A low-cost, energy-efficient, and scalable IoT-based smart parking system is required, ensuring real-time monitoring, seamless data transmission, and dependable performance. This paper examines the ESP8266 as a more efficient solution for smart parking applications.

This paper seeks to assess the power consumption, real-time performance, and cost-effectiveness of the ESP8266 while examining its capacity to communicate parking data efficiently over wireless networks. Furthermore, it aims to evaluate its performance against current microcontroller-based smart parking solutions and investigate its scalability for extensive implementations. The smart city represents the optimal environment for implementing smart parking systems utilizing IoT technology. This study illustrates the viability of employing the ESP8266 for effective parking management, thereby advancing low-cost, energy-efficient IoT solutions in smart cities.

Literature Review:

Every day's existence of people depends on transportation systems [8]. As smart parking systems developed, they changed drastically. Early parking systems depended on limited connectivity and data-sharing capabilities for manual monitoring or simple sensor-based automation. Modern systems now combine real-time data transmission with wireless connectivity, cloud computing, and artificial intelligence to let customers remotely monitor parking availability. IoT-based parking systems can, according to research, save time, ease traffic congestion, and improving urban mobility. There are several Methods proposed, like ultrasonic sensors, are cloud-integrated.

Many research studies on the value of implementing smart parking systems abound, using Smart Cities' IoT-Based ESP8266 [9]. For uses in smart parking, the studies have evaluated Arduino, Raspberry Pi, and ESP8266. Despite its extensive use in IoT applications, Arduino lacks built-in Wi-Fi capabilities, necessitating the use of other modules such as ESP8266 or GSM shields, which add expense and complexity. Although Raspberry Pi uses more power and depends on a consistent power supply, which makes it less suited for battery-operated systems, it provides exceptional processing capability and allows high-level programming; hence, it is fit for AI-driven parking solutions.

Although there are several ways to employ smart parking systems nowadays, most of them are used and have a high financial cost, which deters their use in different ways [10]. Applications By means of real-time data collecting, cloud integration, and automated decisions-making, IoT has transformed parking management. Studies show that smart parking enabled by IoT cuts fuel usage and up to 40% of search time, increasing general efficiency. To guarantee seamless data flow between parking sensors and cloud platforms, researchers have looked at several communication protocols, including MQTT, HTTP, and CoAP. The ESP8266 has become rather popular because of its ability to support several protocols, fast data transfer, and easy integration with IoT systems.

An IoT is dynamically present in the new connectivity paradigm of our daily items, which feature radio modules, microcontrollers, and suitable communication protocols [11]. Any smart parking system depends on reliable communication, which calls for flawless data flow among sensors, cloud servers, and mobile apps. For parking automation, studies of several wireless technologies, including Wi-Fi, LoRa, Zigbee, and Bluetooth, have examined LoRa and Zigbee, which lack fast data transfer and need dedicated gateways even if they provide long-range communication with minimal battery consumption. Urban smart parking systems would find the ESP8266 perfect since it offers a direct and reasonably priced cloud connection with its built-in Wi-Fi module.

The growing proportion of elderly persons in civilisations all around influence smart parking systems most of all [12]. Notwithstanding developments, some issues still exist in smart parking system implementation, including high implementation costs, power efficiency, network security, and scalability. Particularly with the cloud-based parking systems, security issues, including data breaches, illegal access, and cyber threats, have been found to be major hazards. Implementing secure communication protocols, data encryption, and multi-layer authentication seems to help to reduce these hazards, according to studies. Energy efficiency is still a major issue as well; researchers concentrate on low-power microcontrollers, energy harvesting, and the best sleeping modes to extend battery life.

The idea of smart cities has evolved to satisfy the needs of interrelations in terms of communication [13]. Although the body of current research emphasizes several smart parking solutions, few studies concentrate on the relative effectiveness of ESP8266 vs Arduino and Raspberry Pi for mass installations. While most studies stress overall IoT-based parking models, they lack a thorough analysis of cost efficiency, data transmission speed, and power usage for practical applications. This work attempts to close this gap by means of a thorough investigation of an ESP8266-based smart parking system, evaluating its scalability, real-time data processing, dependability, etc. The results will help to maximise reasonably priced, energy-efficient IoT solutions for urban parking control.

ESP8266 CONTROLLER:

Sensitive data on the Internet helps I-OT expand by enabling smart parking systems [14]. Designed by Espressif Systems, the low-cost, Wi-Fi-enabled microcontroller ESP8266's compact design, energy economy, and integrated wireless functionality help to greatly expand Internet of Things (IoT) applications. Designed with built-in Wi-Fi, the ESP8266 is ideal for wireless communication-based projects unlike traditional microcontrollers depending on outside Wi-Fi modules. Among other fields, smart home automation, industrial monitoring, and intelligent traffic management have become much more appealing. Thanks to its low power consumption and great processing capacity, the ESP8266 has evolved as a preferred choice for real-time data collecting, transmission, and remote monitoring in IoT-driven systems. as seen in Figure 1.

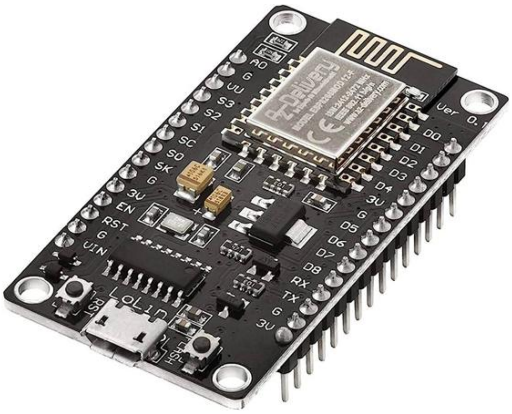

Fig (1): ESP 8266

Researchers have conducted several investigations to evaluate the effectiveness of ESP8266 use. Running on a 32-bit Tensilica L106 CPU, it operates at an 80–160 MHz frequency, therefore balancing computational performance with energy economy. Including up to 4 MB of flash memory, 96 KB of data RAM, and 64 KB of instruction RAM enables the execution of sophisticated IoT applications [15]. The IEEE 802.11 b/g/n Wi-Fi module supports station and access point (AP) modes, therefore enabling local server capabilities or networking connection. The adaptable answer for embedded systems is the ESP8266 since the GPIO, SPI, I2C, ADC, and PWM interfaces offer broad connectivity choices for sensors and external devices.

Unlike the studies already mentioned, there were several ways to enhance smart parking. Smart lighting can be automated in line with ambient light levels by connecting an LED and a light sensor to an ESP8266. Calculating the ambient light intensity, the light sensor—an LDR or BH1750—transmits either an analogue or digital signal to the GPIO pin of the ESP8266. With this data, the ESP8266 decides whether to turn on or off the LED. When the sensor detects low light levels, e.g., at night, the ESP8266 could independently turn on the LED, therefore simulating an automatic street lighting system or indoor smart illumination [16]. Pulse width modulation, or PWM, lets one alter the LED's brightness in step with ambient light levels. The ESP8266 can improve this setup and allow remote monitoring and control by streaming real-time data to a cloud platform or mobile app [17]. Every node was connected inside a mutual range, allowing other node discovery. This approach is best for IoT-driven smart homes and smart cities since it enhances energy efficiency and automation. As displayed in figure 2.

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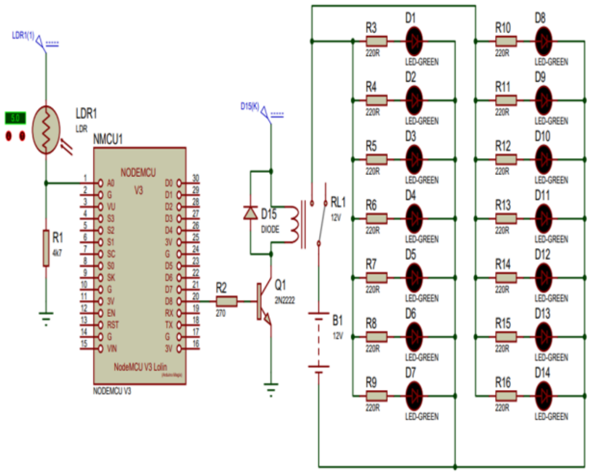

Fig (2): Connected light sensors and LEDs to ESP

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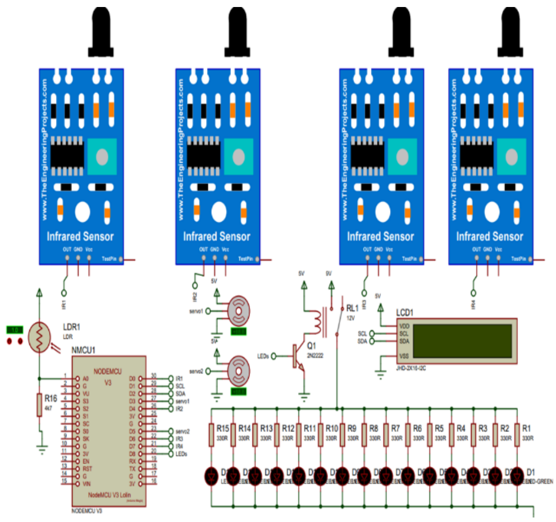

Fig (3): Final circuit to connect all devices

COPARE BETWEEN ESP8266, ARDUNIO, AND RASPBERRY PI

Designed by Espressif Systems, the 32-bit microcontroller known as ESP8266 boasts an 80–160 MHz Tensilica L106 CPU. Built-in Wi-Fi networking helps it to be suitable for low-power IoT uses. On the other hand, less powerful than ESP8266 Arduino boards, such as the Arduino Uno use an 8-bit AVR microprocessor (ATmega328P) running at 16 MHz. The Raspberry Pi, in the meantime, is a single-board computer (SBC) with a 1.5 GHz multi-core ARM processor that can run fully-fledged operating systems, including Linux (Raspberry Pi OS), not a microcontroller. The Raspberry Pi minicomputer needs an operating system; Raspbian was chosen for its simplicity, dependability, speed, and wide development [21]. Consequently, the Raspberry Pi is more power-hungry than the ESP8266 and yet more powerful.

ESP8266's built-in Wi-Fi module allows it to interact via the internet without outside components, so one of its main benefits over Arduino is that Arduino lacks native Wi-Fi, Bluetooth, or Ethernet; hence, extra shields or modules like ESP8266 or GSM modules are needed for wireless connection. Operating on simple-to-ease tasks, Arduino is a microcontroller. It is a platform with open sources. One can obtain a surveillance monitoring system [22] with Arduino. Conversely, Raspberry Pi is more flexible for advanced networking uses since it supports Wi-Fi, Bluetooth, and Ethernet. But the ESP8266 runs much less power than the Raspberry Pi and is best suited for lightweight IoT chores.

Perfect for battery-operated IoT devices, the ESP8266 is quite energy-efficient with a deep sleep mode that lowers power consumption to as low as 10 µA. Though it uses somewhat more energy, Arduino's simplicity and inexpensive cost make it appropriate for embedded devices and energy requirements. Raspberry Pi, being a full Linux-based system, requires at least 5V at 2.5A, consuming significantly more power than ESP8266 and Arduino. This makes the ESP8266 the best choice for low-power, always-on IoT applications like smart parking and environmental monitoring.

The Raspbian Linux version accessible for Raspberry and a smart power meter built on Arduino offer the complete features required for node control [23]. Beginner-friendly for embedded system development, Arduino is programmed using the Arduino IDE using C/C++. Using the Arduino IDE, MicroPython, or Lua, the ESP8266 can also be programmed with additional freedom, supporting advanced web-based communication protocols including HTTP, MQTT, and WebSocket. Though it runs on a complete operating system, Raspberry Pi supports Python, Java, C++, and Bash scripting, among other programming languages. Perfect for IoT uses, the ESP8266 provides a mix between Arduino's simplicity and Raspberry Pi's sophisticated networking capacity.

Applications in the Internet of Things where cheap cost, Wi-Fi connection, and low power consumption are important, like smart parking, home automation, and wireless sensor networks, are where the ESP8266 is most suited; that is, the ESP8266 offers remote control of access for vehicle sensors, allowing users to safely enter and leave their vehicles without personal attendance [24,25]. Mostly utilised in basic automation, robotics, and hardware prototyping, where wireless connectivity is not the major emphasis, Arduino is Being a mini-computer, Raspberry Pi finds use in media servers, edge computing, artificial intelligence, and sophisticated computing projects [26-28]. Although Raspberry Pi is really strong, it is not ideal for low-power IoT devices like ESP8266. Table 1 depicts comparison pare between esp8266, Arduino, and raspberry PI.

Table (1): Comparison pare between ESP8266, Ardunio, And Raspberry PI.

Feature	ESP8266	Arduino	Raspberry
Architecture	32-bit Tensilica L106 (80-160 MHz)	8-bit AVR (16 MHz)	64-bit ARM Cortex-A72 (1.5 GHz, Quad-core)
Connectivity	Built-in Wi-Fi (802.11 b/g/n)	No built-in Wi-Fi (requires shield)	Built-in Wi-Fi, Bluetooth, and Ethernet
Power Consumption	Very low (Deep sleep mode: ~10 µA)	Low (~50 mA)	High (~700 mA to 2.5A)
Programming Languages	C++, MicroPython, Lua	C/C++ (Arduino IDE)	Python, Java, C++, Bash, etc.
Operating System	None (runsirmware)	None (bare-metal programming)	Linux-based OS (Raspberry Pi OS, Ubuntu, etc.)
Processing Power	Medium (for IoT applications)	Low (for simple automation)	High (can handle complex computations, AI, and graphics)
Best Used For	IoT applications (smart parking, home automation, sensors)	Embedded systems, robotics, basic control applications	Advanced computing, AI, media servers, complex networking

Table 1 compares the ESP8266, Arduino, and Raspberry Pi in terms of architecture, connectivity, power consumption, programming support, operating systems, processing capability, and suitable applications. The ESP8266 provides a practical balance between computational performance, energy efficiency, and wireless connectivity. Its 32-bit Tensilica L106 processor and integrated Wi-Fi make it particularly suitable for Internet of Things (IoT) applications requiring wireless data transmission and remote monitoring. Moreover, its extremely low power consumption in deep-sleep mode enables its use in battery-operated applications such as environmental sensors, smart parking systems, and home automation devices.

Arduino platforms, particularly the Arduino Uno, use an 8-bit AVR microcontroller and provide relatively limited processing capability compared with the ESP8266 and Raspberry Pi. Although Arduino does not include built-in Wi-Fi and may require an external communication module or shield, it remains highly suitable for simple embedded control, robotics, and real-time automation because of its straightforward programming environment, low power consumption, and reliable hardware-level operation. Conversely, the Raspberry Pi offers the highest processing performance through its 64-bit multicore ARM architecture. It also provides integrated Wi-Fi, Bluetooth, and Ethernet connectivity while supporting Linux-based operating systems and multiple programming languages.

Conclusion

Designed for the Internet of Things, the ESP8266 smart parking system has displayed amazing remote monitoring, data transfer, and real-time car identification. Low power consumption, integrated Wi-Fi, affordability, and scalability as an automatic parking system, all of which contribute to making the ESP8266 the best option. Unlike conventional parking systems depending on human supervision or cable transmission, this technology allows flawless automation, therefore reducing traffic congestion and increasing space use. Large-scale IoT systems would fit ESP8266 rather well under their better performance, cost-effectiveness, and power economy over rivals like Arduino and Raspberry Pi. Even although its connectivity with many sensors and cloud platforms provides value, the low-power mode extends battery lifetime. Good integration of the ESP8266 in smart parking systems lowers traffic congestion and fuel consumption, therefore boosting user convenience and aiding smart city projects.

General development in ESP8266's scalability, durability, and efficiency make more sophisticated and intelligent urban transportation choices made feasible in IoT-based smart parking systems. Future developments could concentrate on the integration of artificial intelligence for increased security components and predictive parking analytics, therefore boosting the efficiency and impact of the system. Apart from their performance, modern encryption methods and their integration with artificial intelligence-driven analytics improve the security and dependability of the ESP8266-based system. The system may project parking demand patterns and dynamically modify availability or price in real time using machine learning techniques. Future research and development could centre on local data processing via edge computing, hence lowering latency and dependency on cloud technologies.

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