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Intelligent Smart Car Parking System Using Deep Learning and Internet of Things

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Abstract— Parking problems are more acute in contemporary cities due to the rising urban population and the exponential growth of cars in the city. Traditional parking operations can be sub-optimal, may not offer real-time insight, and can lead to higher congestion, fuel usage, environmental impacts and driver frustration. While some of the existing parking solutions are partially automated using IoT, many of them are based on a hardware-based sensor deployment or on traditional Optical Character Recognition (OCR) number plate recognition techniques that struggle with varying environmental conditions and accuracy. This paper proposes an intelligent smart car parking system, which utilizes Internet of Things (IoT), Deep Learning, Computer Vision, and predictive analysis to improve the parking management process. The proposed framework further developed a previously designed IoT based prototype to include YOLO based Automatic Number Plate Recognition (ANPR), camera-based parking occupancy detection and machine learning based parking demand forecasting. The system automates the identification of vehicles, parking space allocation, monitoring of vehicle parking and exit management with less human involvement. The embedding of predictive features allows for proactive decision making and optimization of the use of parking resources. The proposed framework's effectiveness in smart city contexts and ITS applications is confirmed by the improvements in various metrics, including scalability, reliability, recognition performance, and operational efficiency, shown through comparative evaluation.

Keywords: Smart Parking, Internet of Things, Deep Learning, YOLO, Automatic Number Plate Recognition, Computer Vision, Predictive Analytics

I. INTRODUCTION

Urbanization has sped up the number of vehicles in use within cities, putting a significant strain on the existing transportation network. An efficient parking management is one of the many problems urban mobility poses. The lack of adequate parking and inefficient parking operations can lead to traffic congestion, higher fuel consumption, pollution and driver frustration. Considerable portion of urban traffic is due to the search for empty parking spaces leading to unnecessary circulation and loss of transportation efficiency. Most of the traditional parking system is manual or uses only a few limited automation techniques. The common information that these systems provide for parking availability is quite limited, and they are not very successful in directing users to available parking. This has led to a considerable amount of time being spent by drivers trying to find appropriate parking spaces, which leads to delays in travel times and inefficiency in operations. The advent of the Internet of Things (IoT) has revolutionized the evolution of Intelligent Transportation Systems (ITS), allowing for the ability to connect and share data, information and communications amongst various sensors and devices. Smart parking solutions with IoT technologies can be used to monitor and manage parking infrastructure in real-time and centralize the parking resources. However, these benefits are available, many of the existing systems mandate specific sensors be installed at specific parking locations. In addition to the installation costs, an increased maintenance requirement and scalability problem, these sensor-based solutions add to the system [5] and [10]. In addition, the usefulness of such systems is limited by the need for reactive operating modes to occur after parking events.

Vehicle Identification is another crucial aspect of Intelligent Parking System. The traditional Automatic Number Plate Recognition (ANPR) methods are mostly optical character recognition (OCR) based methods that involve a lot of image processing, segmentation and feature extraction using handcrafted features. However, in practical environments like illumination changes, motion blur, shadows, bad weather and viewing angle changes, the performance of OCR-based systems is severely affected [16] – [20]. These limitations prevent them from being applied in real life applications that have very dynamic environments. Intelligent Transportation System capabilities have been greatly improved by the advancements of Artificial Intelligence (AI) in recent years. In particular, the Deep Learning approaches have proven to be exceptionally successful in image recognition, classification and object detection.

Recently, the YOLO family of algorithms have gained considerable popularity because of their high accuracy in object detection and low computational cost, while maintaining the ability of detecting objects in real time. [11]–[15] Unlike conventional approaches, deep learning models learn sophisticated visual representations directly from the data and thus are more robust and do not require manual feature engineering. They have these properties so they're very good for vehicle detection and license plate recognition.

With the development of deep learning technology using vehicle recognition, computer vision technology has emerged as an effective alternative to parking occupancy monitoring. A camera-based system for occupancy detection can monitor multiple parking spaces at once, and doesn't need individual sensors for each space. Therefore, there is a reduction in hardware and scalability and cost-effectiveness [21]–[25]. Moreover, predictive analytics enables intelligent parking systems to shift from reactive to proactive, by offering actionable insights and recommendations based on the prediction of future parking demand. Historical parking trends can be analysed using forecasting methods and the parking resources can be optimized to help manage parking congestion by predicting future requirements [29, 30].

The developed work in this paper is based on an earlier prototype project done in Phase-1 which is a combination of IoT technologies and OCR based number plate recognition for basic entry and exit operations. The first successful application proved the concept of parking automation, but had drawbacks in terms of recognition failure rates, adaptability, scalability, and lack of predictive capabilities. To overcome these limitations, the proposed Phase-2 solution is based on embedding an IoT infrastructure within a YOLO-based ANPR, computer vision-based parking occupancy detection system, and predictive analysis in a single system. These technologies are integrated within the system, which improves operational efficiency, reduce hardware dependency, reduce human intervention and allow for intelligent decision making in the urban parking environment.

II. LITERATURE REVIEW

With the increasing need for an efficient urban mobility, research in the field of intelligent parking management systems has gained momentum. Smart parking technologies have come a long way, thanks to recent developments in the field of Internet of Things (IoT), Deep Learning, Computer Vision, and predictive analytics. Previous works have covered some of the individual components of parking automation, but most focus on one component, whether on the occupancy detection system or on the vehicle identification or communication system, without offering an integrated system that facilitates intelligent decision making.

As a key technology, IoT has become a cornerstone of the smart city infrastructure and intelligent transportation sector. An IoT-based parking system leverages sensors, the internet, wireless technologies and cloud services, along with a mobile application, to deliver parking availability and status information in real time. These systems will enhance the user experience and enable easy tracking of parking resources from a central location. Atzori et al. called IoT an enabling paradigm for interconnected environments that are able to support a range of urban applications [7]. Likewise, there have been a number of studies that have pointed out the possibility of using an IoT-based parking automation system for congestion management and improved parking utilization by gathering and communicating parking information automatically [4], [5]. While all these benefits exist, many current parking deployments around IoT technologies require deployment of a large number of sensors at the individual parking spaces. In the case of sensor-based approaches, however, the cost and complexity of the installation and maintenance may increase with multiple ultrasonic, magnetic, infrared or inductive sensors in each slot. They are high performance designs and difficult to implement in large parking lots because it requires a lot of hardware [5] [10]. Thus, in real deployments considerations of scalability and long-term operational sustainability are significant issues.

Two key aspects of intelligent parking systems are vehicle detection and Automatic Number Plate Recognition (ANPR). The main type of traditional vehicle identification system relies on Optical Character Recognition (OCR) which is based on image processing, segmentation and feature extraction based on handcrafted features. These techniques work well when lighting, shadows, camera movement, camera angle and weather are controlled, but are not effective in uncontrolled environments with poor lighting, shadows, movement, different camera angles, and poor weather. It is therefore clear that OCR-based methods are not always adequate for large scale applications [16]–[20]. AI and Deep Learning are revolutionizing Object Detection and Recognition in ITS. Convolutional Neural Networks (CNNs) have shown outstanding performance in the ability to learn hierarchical visual representations directly from raw data without engineering features manually. These models have been able to show state-of-the-art performance in image classification, object detection and pattern recognition tasks [23], [36]. The YOLO family of algorithms has drawn a lot of attention as an accurate deep learning-based object detector that can localize and classify objects in real time [9], [33].

The drawback of YOLO is that it uses a one-stage detection method, which is faster than the two-stage detection method used by traditional detectors but has higher computational requirements. YOLOv4, YOLOv5 and YOLOv8 have been recently developed, which further enhanced detection performance under challenging operating conditions such as low illumination, partial occlusion and complex background [13]–[15].

Occupancy detection is another essential aspect of smart parking systems, besides vehicle recognition. The conventional methods used for parking space occupancy measurement are based on the use of dedicated sensors placed in individual parking spaces. These methods can achieve good accuracy, but they make implementation and maintenance difficult. Recent computer vision research has resulted in camera-based parking space occupancy monitoring systems that are able to monitor several parking spaces at once. The systems analyze the visual information received from surveillance cameras, eliminating the need for manual intervention and improving the scalability of the system [21]–[25]. The vision-based occupancy detection has thus become a viable solution in a smart parking scenario. Most of the smart parking solutions available in the market offer real time information on the parking status of the parking space, but operate in a reactive way. These systems only react to parking events and are unable to predict demand changes. Predictive analytics is designed to overcome this by analysing past parking data to pattern users' behaviour and predict future usage levels. Time-series forecasting and machine learning models help in proactive management of resources, optimisation of slot allocation and traffic congestion during peak periods [10], [29], [32]. Introducing forecasting mechanisms into parking infrastructure brings a new layer of intelligence which can be useful for strategic planning and parking operation optimisation.

From the literature survey it is found that most of the proposed systems are targeted towards isolated functions instead of fully integrated system. While sensor-based parking systems have a tendency to be hardware dependent and fail to scale, OCR-based parking recognition methods have difficulties in a variety of scenarios. Occupancy monitoring and predictive analytics are separate fields of research that are sometimes studied in isolation from each other, rather than as part of a single operational approach. In addition, many current systems are restricted to a reactive approach to decision making and do not have any means for forecasting future parking demand.

III. PROPOSED SYSTEM METHODOLOGY

The Intelligent Smart Car Parking System (ISCPS) will be proposed to solve the drawbacks observed in the conventional parking infrastructures and the previously developed Phase-1 implementation. It integrates the IoT infrastructure with deep learning, computer vision, and predictive analytics to deliver an intelligent and scalable parking management solution. The proposed architecture has automated the vehicle identification, parking allocation, monitoring of vehicle occupancy, and exit management and enabled the use of data to inform decision making. As a car enters the parking area, the system starts its functioning process. The camera captures the image of the vehicle as it arrives and the image is processed to identify the vehicle and then to find the matching license plate. The recognized number plate is then compared to the parking database to see if the vehicle is being used for the first time or if the vehicle has been registered. An appropriate slot is assigned and recorded in the system database, based on parking availability. The parking status is checked continuously during the parking process, which allows to update the parking availability in real-time. When the car leaves, the identification procedure is repeated to verify that the car is the one that is leaving, to clear the occupied slot and to update the parking history.

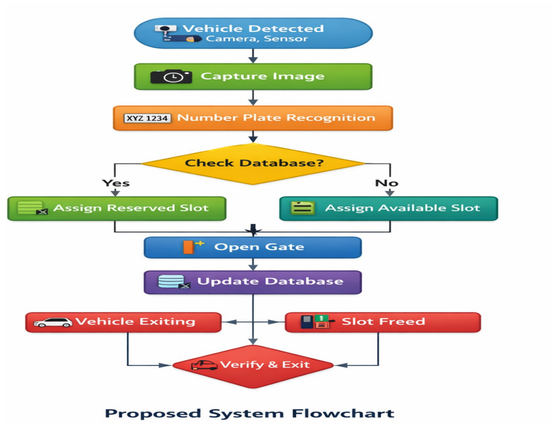

Fig. 1. The proposed intelligent smart parking system and its workflow

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In the proposed methodology, the automatic number plate recognition is used as a key technique in the vehicle identification process, which leverages deep learning techniques. The method differs from traditional OCR methods by using the YOLO object detection network to detect and identify license plates via visual information. With deep learning models, discriminative features are automatically extracted from training data, which makes the model more robust under various operating conditions. YOLO can be used to meet the requirement of real-time processing and achieve high-speed detection and accurate localization, which is suitable for intelligent transportation applications [3], [9], [23]. The OCR-based recognition approach was replaced by YOLO-based ANPR to overcome several drawbacks in the previous Phase-1 implementation. Inspired by this, the system achieves better robustness to illumination, shadow, camera orientation and partial occlusion, improving the reliability of recognition in a practical deployment environment [13], [23]. This means that vehicle identification is more precise and not so reliant on extensive preprocessing processes.

The proposed framework also uses computer vision based parking occupancy detection tool to replace the typical hardware intensive sensing tools. A camera system is strategically placed around the parking environment and is able to capture multiple parking spaces at once. Parking slot image processing methods are used to determine if a parking slot is full or empty by visual inspection. This method eliminates the need for separate parking space sensors, and makes installation and maintenance easier [1], [3], [9]. It is especially scalable and cost-effective to be able to observe multiple parking spaces with a single camera system.

The system also includes predictive analytics capabilities that leverage its data to help with pro-active parking management. The system also features real-time monitoring capabilities, integrated into their system for proactive parking management. Occupancy data from past parking operations is analysed in order to determine if there are recurring demand patterns and temporal trends.

Forecasting functions are used to anticipate what capacity the parking system will need in the future and assist it to optimise the use of the parking slots, thereby avoiding the congestion that occurs during peak times. Predictive analytics can help optimize the parking process by making it more proactive and a decision support system for users, thus increasing the operational efficiency and user satisfaction. The proposed system has a modular design with multiple layers, ensuring scalability, flexibility, and modularity. Sensors such as cameras and communication devices are part of the sensing layer, collecting information from the environment. The Edge Computing processing layer detects vehicles, recognizes the number plates, classifies the vehicle occupancy and analyses data. Processed data is then sent to the cloud and database tier where parking and occupancy data and predictive analytics are stored [6],[17],[20],[21]. The application layer displays the parking information, occupancy status and operational status to the users and administration control.

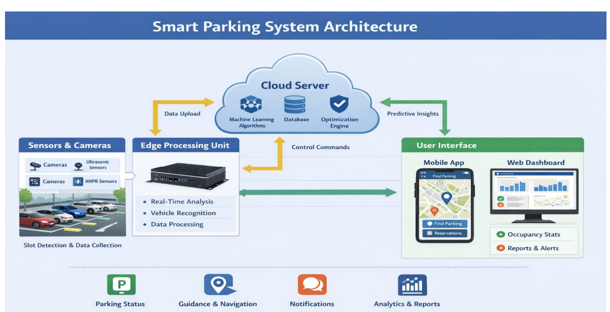

Fig. 2. High level system design of the proposed Intelligent parking system that is Sensing, Edge processing, Cloud Services, User interface

By combining the IoT infrastructure with deep learning-based recognition, computer vision-based occupancy detection, and predictive intelligence into a single, cohesive system, the proposed Phase-2 system can overcome some of the drawbacks of traditional parking methods. The methodology offers a basis for effective, scalable and intelligent parking management that can be used in smart city settings.

IV. IMPLEMENTATION AND RESULTS

The proposed intelligent smart parking system was implemented The main operation functions of the parking operation were automated with the implementation of the proposed intelligent smart parking system using software framework that involves image processing, database management and parking control mechanisms. It is geared towards Vehicle Detection, Number Plate Recognition, Slot Allocation, Occupancy Management and Exit Processing.

The goals of the implementation were to show that the proposed Phase-2 architecture was viable and to assess the benefits of this to the previous phase developed architecture (Phase-1). The software environment was developed using Python, as it has a large number of support for computer vision, database management and machine learning applications [11]. The software employed for acquiring the image used was OpenCV and for the image processing operation was OpenCV and for the database interaction SQLite was used. Multiple function modules were implemented in the implementation architecture, for the purpose of implementing different parking operations in an integrated way.

The image capture module was the key component between the physical parking environment and the processing system. The cameras at specific entry/exit points were continually collecting the visual data related to the vehicles approaching. The captured frames were then transmitted to recognition module for further processing. This phase is defined as implementing deep learning based car identification methods in the proposed framework, which enhances the reliability of license plate recognition in varying scenarios. The recognition module was used for the number plate recognition application for the vehicles entering and leaving the parking area. Recognized license plate information was then compared to current parking information in the system to ascertain whether the vehicle was in operation or not. The verification of the databases allowed the system to differentiate between new vehicles entering the parking area and vehicles already registered in the database and thus also made reliable access management possible.

The database management module stored information for vehicle identification, parking slot assignment and parking time. Whenever a vehicle went into the car park, the car park server would record all relevant data and update them in real-time during the parking process. As vehicles departed, the information on these records was updated to free up an occupied resource and ensure consistency in the vehicle's occupancy. The parking slot allocation algorithm automatically determined the parking slot based on available vacant parking slots. If the vehicle is identified and verified successfully, the system allocated a suitable parking slot and changed the state of the parking lot in the database. In the same manner, as soon as a vehicle left the parking facility the parking slot was released and re-added to the parking resource pool. Automated management process eliminated manual involvement and avoided delays in operation. The overall implementation was in line with a sense–decide–act paradigm. The sensing part of the framework was the information obtained from the visual elements by means of cameras. The decision stage consisted of vehicle identification, verification with the database, determination of occupancy and allocation of slots. Finally, the identified actions were implemented by making database changes and occupancy changes to ensure that accurate parking information is available during the operational cycle.

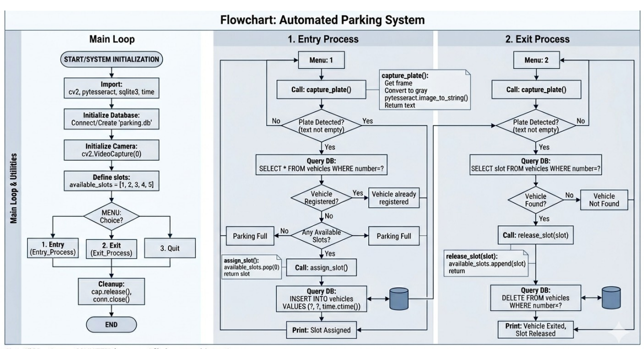

Fig. 3. Specified implementation flow for the system, system initialization, entry control, database operation, parking control, exit control

The operational order of the framework that was implemented started with the arrival of the vehicles at the parking entrance. The vehicle was detected and recognized by the recognition module. Once the vehicle was identified successfully, the parking database was checked to find out the status of the vehicle. When parking spaces were free, a suitable space was allocated and the availability updated. During the entire parking period, the parking status was monitored continuously to give real-time parking information. At the moment of leaving, the departing vehicle was identified again and the corresponding parking space was unlocked and the parking information was recorded as completed. The impact of the proposed framework was evaluated by comparing the Phase-2 system to the previous phase-1 system. The focus in the comparison was on the efficiency of communication, energy use, scalability and operational performance. Based on the results, it can be concluded that the developed architecture provides tremendous improvements for several performance metrics.

Moving away from Wi-Fi communication and towards low-power wide area networking technologies resulted in decreased energy consumption and increased battery life. A reduction in transmission frequencies led to lower energy consumption without compromising on good parking management. Where large deployments are concerned and communication distances are significant, maintenance is a low priority, and it was especially useful to use LoRa technology [2]. A wider comparison of the properties of the two phases also shows the technological changes that have been developed in the proposed system. The main emphasis on the Phase-1 system was automation of entry and exit operations by employing the technique of IoT and OCR. The Phase-2 architecture, on the other hand, integrated deep learning and computer vision technologies to enable intelligence and predictive capabilities.

Performance Aspect	Phase-1	Phase-2
Number Plate Recognition	OCR-Based	YOLO-Based ANPR
Recognition Robustness	Sensitive to Environment	Improved Robustness
Parking Occupancy Monitoring	Sensor Intensive	Vision Based
Decision-Making Capability	Reactive	Predictive
Automation Level	Partial	Intelligent Automation
Scalability	Limited	Enhanced
Hardware Complexity	High	Reduced
Operational Efficiency	Moderate	Improved

Table 1: Comparative Analysis Of Phase-1 And Phase-2 Systems

The comparative evaluation shows that the proposed system overcomes the major drawbacks of the previous one. The use of YOLO recognition has greatly enhanced the ability of vehicle recognition under different environmental conditions. Compared with OCR methods, deep learning-based detection is able to maintain good performance in actual deployment scenarios, which is difficult for OCR methods due to varying lighting conditions and image quality. Replacing the hardware intensive occupancy sensors with the camera monitoring also plays an important role in scalability and cost effectiveness [1], [3], [9], [23]. A single visual infrastructure can simultaneously monitor multiple parking spaces, which can help to streamline installation and minimize maintenance needs. This is particularly advantageous in large parking areas where traditional parking sensor technologies are not cost effective.

The Phase-2 plan suggests one of the largest changes is to embrace predictive analytics. The traditional parking system operates on a reactive basis, only reacting when they detect changes in parking use. The proposed system, on the other hand, leverages past parking data to detect the usage patterns and forecast future demand situations. Forecasting helps to plan ahead for slot management, optimize resource usage, and reduce congestion in peak parking times. From overall, it could be concluded that the studied experimental results indicate that the proposed intelligent parking system is more efficient, reliable, scalable, and adaptable than the existing one in Phase-1. By integrating the IoT infrastructure with deep learning, computer vision and predictive intelligence, a practical framework is realised to deploy next generation parking system solutions to meet the needs of ITS and smart city applications [6], [17], [20], [21].

V. CONCLUSION AND FUTURE WORK

The need for intelligent parking management technology to overcome the constraints of traditional parking systems has grown in speed and scale with the demand for efficient urban mobility solutions. In the case of the paper, an intelligent smart car parking framework that leveraged Internet of Things (IoT), Deep learning, Computer vision, and predictive analytics was presented in order to enhance the parking operations in modern urban scenario.

The proposed Phase-2 architecture is a great improvement to the IoT–OCR based prototype developed in Phase-1. The implementation of Automatic Number Plate Recognition (ANPR) using YOLO algorithm improved the robustness and reliability of the system for vehicle identification in different environments, overcoming some drawbacks of the traditional OCR system. The implementation of computer vision based occupancy monitoring led to the elimination of the requirement for large platforms of sensors and instead it proposed to monitor multiple parking spaces using the camera infrastructure. Such change improved the scalability, system complexity and maintainability.

Predictive analytics was also an important feature that was introduced in the proposed model. The system went from a reactive approach to an operational model to a proactive approach to a decision support model, using historical occupancy and forecasting. This foresight enables better use of the parking resources, optimal allocation of the parking spaces, and congestion minimization during peak periods. From a communication perspective, low-power wide-area communication technologies did deliver energy efficiency benefits, and added to the potential viability of deploying in large quantities with long service lives. Furthermore, the proposed system was hierarchical in its system design and allowed for flexibility, modularity, and adaptability by integrating the different functions of sensing, processing, communication, and application into one system.

The comparative study helped the researchers come to the conclusion that the proposed Phase-2 system's recognition ability, operational efficiency, scalability, reliability, and intelligent decision was better than Phase-1 system. The results suggest that the proposed framework has a potential scope of being implemented in the smart city transportation infrastructure and is practical and effective in intelligent parking management. The proposed framework shows good performance, but there is scope for further development that will increase its capability and applicability. Autonomous vehicle systems can be incorporated with future intelligent parking systems to enable fully automated parking with reduced user interaction. By implementing blockchain mechanisms, these systems can further enhance the transparency, security, and trust in transactions, including the secure reservation system and automated payment processing. In addition, dynamic pricing models can be used to optimize parking use and behaviour based on the real-time demands and booking situations. Furthermore, having advanced urban data analytics and large-scale deployment can offer useful information on long-term transportation planning and sustainable mobility initiatives. As new technology becomes a part of ITS, its role is crucial in solving the increasing mobility issues of modern cities.

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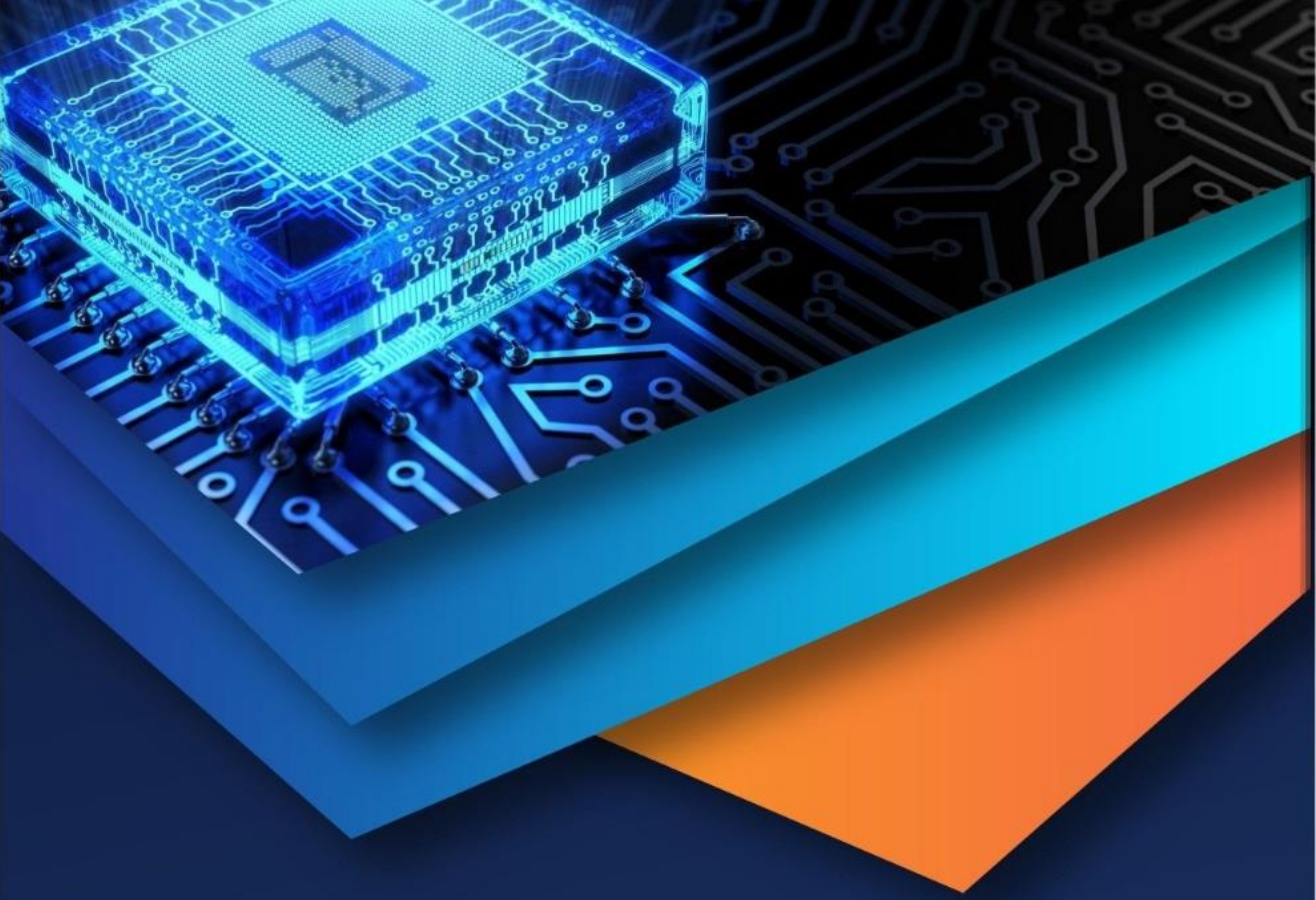

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