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Contactless IoT-Based Smart Doorbell and Vehicle Number Plate Detection System for Industrial Access Control

V. Elumalai[1], Gayatri Tharani S[2], Devanayaki V [3], Dhanushree P [4], Dharani M[5]
[1]Assistant Professor Department of Electronics and Communication Engineering VSB Engineering College, Karur, Tamil Nadu, India
[2]UG Scholar, Electronics and Communication Engineering VSB Engineering College, Karur, Tamil Nadu, India
Email ID : dhanushreegovindaraj24@gmail.com
[3]UG Scholar, Electronics and Communication Engineering VSB Engineering College, Karur, Tamil Nadu, India
Email ID : tharanisureshani@gmail.com
[4]UG Scholar, Electronics and Communication Engineering VSB Engineering College, Karur, Tamil Nadu, India
Email ID :dharanimani1704@gmail.com
[5]UG Scholar, Electronics and Communication Engineering VSB Engineering College, Karur, Tamil Nadu, India
Email ID :devanayakivdeva@gmail.com

ABSTRACT
The industrial setting demands high-quality, safe, and contactless control measures of vehicle access at the entrance points. Traditional approaches used in manual verification, RFID cards and physical access buttons tend to be characterized by delays in operations, insecurity and high reliance on human supervision. This paper introduces a Contactless IoT-Based Smart Doorbell and Vehicle Number Plate Detection System that aims at automating the industrial gate access with the help of the computer vision and wireless communication technologies. The suggested system will use the camera module to take pictures of vehicles when they arrive at the gate without physical contact with the module. An image-number plate detection and recognition algorithm which is based on machine learning is applied to the received picture and compares the identified number with the previously registered car database. In case of approved vehicles, the processing unit sends an access command to an ESP32 microcontroller over the UDP communication protocol, which allows automation of servo motors in a gate. Real-time visual feedback is also available in the system with the use of LCD display. When it comes to the unauthorized vehicles, its access is denied, and an image of the vehicle is automatically forwarded to the authorized personnel through email alerts to perform security control. The solution that has been proposed will improve security, minimize manpower needs, keep records of digital access and facilitate scalable implementation in the industrial settings. As a result of experimental observations it has been proven that the system is offering efficient, reliable and contactless vehicle access control that fits in modern smart industry.
Keywords: Industrial Access Control, Internet of Things (IoT), Vehicle Number Plate Recognition, ESP32, Computer Vision, Smart Gate Automation, Contactless Security.

1. INTRODUCTION:

As vehicles are rapidly increasing in the industrial campuses, secure and automated access control has become a substantial need. Traditional access control methods like manual verification, physical gate controls, security guards, RFID cards, and physical gate controls have weaknesses such as human error, operational delays, scalability and real-time monitoring. In a bid to address such problems, Automatic License Plate Recognition (ALPR) combined with IoT and intelligent control systems has become a potential option of managing vehicle access, especially in contacts-free and trustworthy ways. Recent research indicates there is great improvement in the vision based gate automation system. Revanth and Namitha [1] came up with a proposal of an automatic gate-opening system, which uses the combination of license plate recognition, vehicle make-model recognition, and facial recognition with a high precision rate of up to 98.4 percent with deep learning networks, like YOLOv7 and ResNet. Although effective, such multi-modal systems raise the cost of deployment and complexity of computation. Chen et al. [2] paid attention to the idea of real-time license plate recognition and vehicle tracking with the use of YOLOv3, demonstrating the ability to realize real-time performance with 40 FPS and referring to the opportunities of using a deep learning system in the realization of the access control and traffic management system. Srividhya and Raju [3] have gone further to introduce advanced zone monitoring systems where they have come up with an effective ANPR system that can deal with non-controlled environment, light conditions and different plate formats and include real time notifications and matching them in a central database. Adaptations by region have also been considered, with Valdeos et al. [4] suggesting a CNN-based license plate recognition system that works with Peruvian license plates, and is nearly perfect at its tasks with the addition of YOLOv4 and OCR. Besides, Abreo et al. [5] have shown that AI-based campus vehicle management system with YOLOv8 and Tesseract OCR on Raspberry Pi is more focused on real-time tracking and enhanced accessibility. Although these have been developed, a lot of the current solutions do not have a smooth integration with lightweight IoT controllers, contactless gate actuation and real time alert systems that can be applicable in industrial settings. It is inspired by these restrictions and suggests an IoT-Based Smart Doorbell and Vehicle Number Plate Detection System that is powered by machine learning-based recognition, ESP32-based gate automation, and real-time alerting to increase the efficiency and safety of industrial access control.

2. RELATED WORKS

The latest technology in Automatic License Plate Recognition (ALPR) systems has been more inclined to enhance the strength, real-time processing, and capability to adjust to region-specific plate format with deep learning algorithms. Abarkan and Akchioui [6] have suggested a CNN-driven model of Moroccan license plate recognition and detection to overcome the issues of Arabic characters, font variability, and the variability of plate format. Their CNN model that admits the Arabic letters and the digits separately greatly enhanced the recognition accuracy and showed that region aware model design is a key to reliable access control system. In the same vein, Abdulkhaleq et al. [7] provided a thin-sliced deep learning-based ALPR system optimized in reference to the Iraqi license plates. Using a Lightweight Convolutional Neural Network (LWCNN), the system was able to have high accuracy in detection as well as low computational complexity. The methodology demonstrates the practicality of implementing the ALPR solution on resource-limited systems, needed by embedded-based and IoT-based access control systems.
Attending to the Indian case, Rabindranathan et al. [8] investigated a computer vision-based license plate detection system which resolves the problem of font variations, skew, blur, and environmental noise. Their pipeline of multi-stage, which includes preprocessing, character segmentation, and recognition, proves that the requirements in the image processing area are strong in the case of working with non-standardized license plate regulations. There have also been advanced real-time ALPR systems based on object detection frameworks that have been reported widely. Derrouz et al. [9] introduced the YOLov3-based real-time ALPR system of Moroccan video streams, which combines vehicle tracking and a post-processing mechanism based on voting to enhance the consistency of recognition. The system was also found to have high detection and recognition accuracy in different environmental conditions which proved that the system is applicable in surveillance and access control applications. Recently, Asaju et al. [10] came up with an automatic plate number recognition system, which utilizes the YOLOv9 model to optimize access control in restricted zones. What is important in their work is the focus on real-time performance, performance in a wide variety of conditions, and the ease of interconnection with the automation system of the gate. The paper proves the usefulness of current YOLO structures in access control of vehicles.
Though these works show high advancement in the ALPR accuracy and the real-time detection, it has not sufficiently focused on complete automation of the gate through a fully developed contactless IoT-based system with real-time alerts, so the proposed system is motivated. Access control systems that are smart and based on automatic license plate recovery (ALPR) have attracted a great deal of attention because they have the power to increase security and minimize human involvement. Kahie et al. [11] provided a prototype of a smart access control of restricted buildings based on vehicle number plate recognition. Their system adopted a Raspberry Pi, camera module, optical recognition algorithms and a gate control based on servo motor. The paper has shown that plate recognition by using images can be effective as it can be used to substitute some form of manual verification especially in a setting where the security officer experience fatigue and inconsistency in surveillance making it prone to attacks. Devisurya et al. [12] have provided advancement in deep learning-based recognition accuracy by introducing an improved number plate recognition architecture of restricted area access control with YOLO variants (YOLOv8 and YOLOv9) combined with EasyOCR. A comparative study when they compared their results with those of several of the detection architectures indicated significant gains in real-time recognition accuracy and reliability supporting the usefulness of integrating object detection models with sophisticated OCR engines in security applications.
Focusing on the issues of regions, Phon et al. [13] created a strong system of Thai license plate recognition through the collaboration of YOLOv5 and EasyOCR. The research was able to high detection, segmentation, and recognition accuracy despite the difficulty of the Thai scripts, low light scenario, and motion blur. The current study highlights the need to use specific datasets and deep learning-OCR hybrids to deploy them in real-world scenarios in access control and intelligent transport systems. J. S et al. [14] investigated real-time data processing and database integration by developing a license plate recognition pipeline and integrating it with a database manager, to be used in smart city applications. Their system had a good compatibility and reproducibility rates with scalable implementation in toll booths, parking systems and security gates and effective logging and monitoring. Ganesh et al. [15] paid attention to an ALPR system based on image processing to provide services on parking and office security. Developed on Raspberry Pi with compiled neural network parameters, it was quite efficient and was still able to control in real-time a graphical user interface. This paper brings out the possibility of using edge based implementations in access control situations.
In recent years, the literature has been devoted to enhancing the accuracy and real-time capabilities of the license plate recognition (LPR) system and the feasibility of its deployment based on the advanced deep learning architectures. Riyadi et al. [16] came up with a vehicle license plate recognition system based on YOLOv8 with PaddleOCR where the Mini PC has been used as a central processing unit. Their system reported 91.6% detection accuracy and showed that YOLOv8 was suitable in applications that need an efficient and reliable plate

recognition system in access control and traffic monitoring. Integrated vehicle analysis systems have also been examined beyond access control. A common system was suggested by Dhonde et al. [17] to detect over-speed and license plate recognition with the help of the YOLOv5 and OCR systems. The system supports the extensibility of deep learning-based detection models on intelligent transportation systems as vehicles can be extracted in video streams and the speed of the system to compute speed before plate recognition. LPR has also been improved further with advancements in object detection architectures. The article by Kumar et al. [18] introduced a transfer learning-based system for real-time license plate recognition based on YOLOv9 to enhance the reliability of detection. Their method obtained a high mean average precision (mAP50) of 99.5% of features showing the ability of YOLOv9 to overcome the traditional LPR constraints with respect to different illuminations, obstruction and plate orientations.

Rao et al. [19] reinforced hybrid deep learning-OCR pipelines, and have come up with an LPR system that combines YOLO to localize plates and PaddleOCR to extract text. The system was checked against some predefined list of authorizations, which is why one can refer to the relevance of the system in automated access control and vehicle authentication systems. As the need to execute real-time load on resource-restricted platforms has risen, edge-efficient LPR solutions have become of interest. The study of Kharrasov et al. [20] explored the optimization of algorithm in the license plate recognition with edge computing restrictions. The assessment of hyperparameter sensitivity and the concept of convolutional recurrent networks of character recognition resulted in the creation of a balanced trade-off between the speed of inference and recognition rates, confirming the possible idea of using LPR in real-time and on edge devices. The initial methods of automatic license plate recognition (ALPR) were based mostly on classical image processing and optical character recognition methods. Firasanti et al. [21] studied a license plate recognition system based on OCR on a Raspberry Pi, and compared Canny Edge detection and Otsu thresholding to segment plates. Their experimental outcomes revealed better edge detection performance with Canny Edge with 100 percent accuracy in detecting edges but the recognition accuracy was low which serves as a limitation to the traditional image processing method in different lighting conditions. As the edge intelligence developed, Kim et al. [22] came up with an AI camera architecture that could automatically recognize a license plate in real time on the machine. The system they used used several CNN models to detect plates and extract characters, with a back-end cloud server to frequently update the model. This hybrid edge-cloud architecture was found to be more accurate, flexible, and scalable, and it is contended that solid system architecture is vital in a real-world installation of ALPR. Focusing on the problems of multi-region license plate recognition, Huang et al. [23] introduced a new model called YOLOv10-LPRNet that was created with the aim of identifying license plates with various regulatory forms. The combined use of YOLOv10 to detect targets and LPRNet to recognize the numbers resulted in high accuracy of the system in cross-border datasets. This paper highlights the importance of multi-object recognition and sequence recognition network in the high-complex traffic conditions with the use of heterogeneous license plate systems. Though these papers reveal much improvement on edge-based recognition, system architecture design and multi-regions adaptability, most of them are mainly concerned with the accuracy of detection and recognition. There is scant literature on fully integrated solutions of access control based on IoT capable of integrating contactless operation, real time decision-making, actuation based on microcontrollers, and alert systems, which drives the design of the presented system. Despite the positive results of these studies in recognition accuracy and automation of access, inadequate attention is given to fully contactless communication based on the Internet of Things, integration with lightweight microcontrollers, and alert mechanisms in real-time, which is a necessity in the current industrial access control system.

Proposed System

The black box proposed system presents a contactless and unmanned vehicle access control system in industrial applications combining computer vision, IoT communication and embedded control. Figure.1 shows a proposed work hardware block diagram.

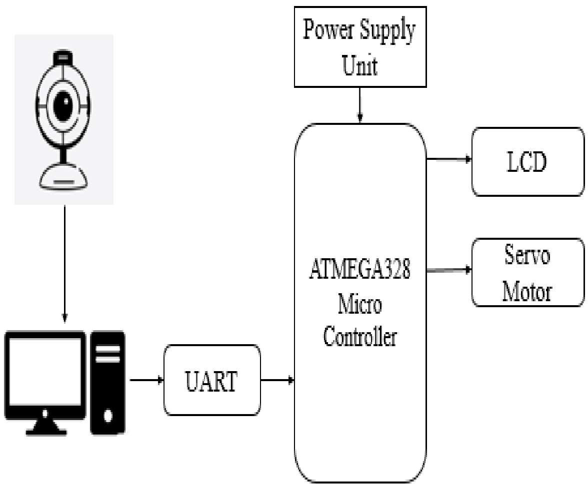

Figure.1 Proposed Work Hardware Block Diagram

The system has been developed to remove human interference at points of entry as well as provide safe and effective access of vehicles. At the entrance to the industry, there is a camera-based monitoring unit that comes to keep track of the incoming vehicles.

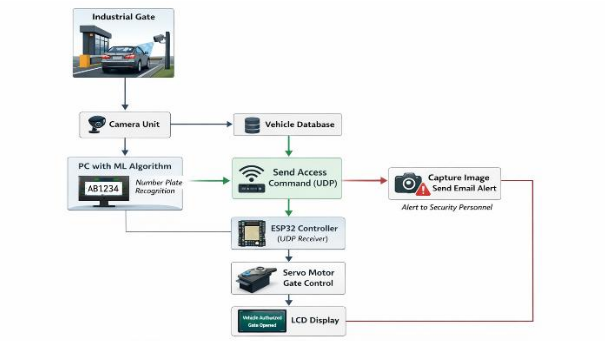

Figure.2 Proposed Work Architecture Diagram

The camera takes an image of the vehicle when it nears the gate and the driver does not have to even touch the camera. This captured image is sent to a processing unit, where it goes through a vehicle number plate detection and recognition algorithm based on machine learning, which is run. The algorithm makes use of number plate localization, character segmentation, and optical character recognition to fetch out the vehicle registration number. The identified number plate is compared with a database that has been pre-registered with authorized vehicle details. This check-up procedure will identify whether the vehicle can access the industrial premises or not. In case the vehicle is recognized as one allowed, an access approval command is created and sent to an ESP32 microcontroller via the User Datagram Protocol (UDP). UDP is chosen because it has a shorter latency and it is appropriate to use in real-time communication within a local network. When the ESP32 gets the approval signal it triggers a servo motor device to open the gate automatically. At the same time, an LCD screen with the microcontroller can give a visual message about the status of access, which is the absence of problems when entering. When the vehicle is not registered in the database, the system blocks the vehicle and leaves the gate closed. The captured image of the vehicle is saved and automatically sent to authorized personnel by email alert system where the security awareness and response can be realized immediately. Figure.2 shows a proposed work architecture design. This is a good characteristic as it improves surveillance and averts unauthorized attempts at entry. In general, the suggested system provides an effective, scalable, and non-contact way of access control to industrial vehicles. The system enhances security, lowers manpower, and facilitates the creation of smart and secure industrial infrastructure by using machine learning-based recognition, IoT-enabled communication, and automated use of a gate.

3. METHODOLOGY

The proposed methodology is aimed at a secure, contactless, and automated vehicle access control system design in the industrial setting, which combines computer vision-based number plate recognition with a gate automation powered by IoT technologies. The system works in a series of synchronized processes, which guarantee right vehicle identification, dependable communicating and live access decision making.

Vehicle Detection and Image Acquisition

The industrial gate has a high-resolution camera which constantly keeps an eye on the vehicle entry point. Once a vehicle comes to the gate, the camera takes a photo automatically and the driver does not have to physically interact with it. This is a contactless acquisition of the image which guarantees clean operation and access delays. The image that is captured is automatically sent to the processing unit to be analyzed.

The methodology begins with continuous visual monitoring of the industrial entry point using a fixed camera module. When a vehicle enters the field of view, an image $I(x, y)$ is captured automatically. To improve robustness against noise and illumination variations, the captured RGB image is converted into grayscale using a weighted transformation as expressed in **Equation (1).**

$$I_g(x, y) = 0.299R + 0.587G + 0.114B \qquad (1)$$

Noise suppression is performed using Gaussian filtering to smooth high-frequency components while preserving edge information. The filtered image $I_f(x, y)$ is obtained as shown in **Equation (2).**

$$I_f(x, y) = I_g(x, y) * G(\sigma) \qquad (2)$$

where $G(\sigma)$ represents a Gaussian kernel with standard deviation σ. Contrast enhancement is then applied using histogram normalization to improve number plate visibility.

Number Plate Detection and Recognition

The image of the received vehicle is pre-processed, i.e. it is converted into grayscale, noises are removed, and contrast is improved in order to increase the detection accuracy. The algorithm of number plate detection is then a machine learning-based algorithm that is used to localize the number plate region in the image. After being identified, the plate area is divided and individual characters are extracted. The segmented characters are converted into a form of alphanumeric text that is the vehicle registration number using optical character recognition (OCR) methods. This is done so that it can recognize properly even when the lighting and the environment are changed.

The enhanced image is processed using a machine learning–based detection model to identify the number plate region. Edge intensity is calculated using gradient operators to emphasize rectangular plate boundaries. The gradient magnitude $M(x, y)$ is computed using **Equation (3).**

$$M(x, y) = \sqrt{G_x^2 + G_y^2} \qquad (3)$$

Bounding regions with high edge density and aspect ratios corresponding to standard license plates are extracted. The candidate region with maximum confidence score C_p is selected using **Equation (4).**

$$C_p = \underset{r \in R}{\operatorname{argmax}} P(r|I_f) \qquad (4)$$

where R represents the set of detected regions and $P(r|I_f)$ denotes the probability of region r being a valid number plate.

Once localized, the number plate region is segmented into individual characters using adaptive thresholding. Binary segmentation $B(x, y)$ is obtained using **Equation (5).**

$$B(x, y) = \begin{cases} 1, & I_f(x, y) > T \\ 0, & \text{otherwise} \end{cases} \qquad (5)$$

Each segmented character is resized and passed through an optical character recognition model. The predicted character class $\hat{c}$ is determined using maximum likelihood estimation as shown in **Equation (6).**

$$\hat{c} = \underset{c \in C}{\operatorname{argmax}} P(c|f_i) \qquad (6)$$

where f_i represents extracted feature vectors and C is the character set.

Authorization and Database Verification

The vehicle number obtained is matched with a pre-registered database of legitimate vehicles. The database is kept in a local location and can be updated by appointed administrators. When a match is made the vehicle is considered authorized, otherwise it is considered unauthorized. This computerized checks and balances access control ensures that there is uniform and impartial access.

The recognized number plate string $S = \{c_1, c_2, \ldots, c_n\}$ is compared against the authorized database. Authorization is granted when an exact match occurs, represented by the decision function in **Equation (7).**

$$A = \begin{cases} 1, & S \in D \\ 0, & S \notin D \end{cases} \qquad (7)$$

where D denotes the set of registered vehicle numbers.

IoT Communication and Gate Control

An access approval signal is sent between the processing unit and an ESP32 microcontroller through the User Datagram Protocol(UDP) on successful authorization. UDP is chosen because of its communication latency and support real-time applications of control. The ESP32 interacts with the command received and does an operation on a servo motor, which is attached to the gate mechanism. The servo motor moves about to open the gate, thereby permitting the authorized vehicle to get into the premises. The ESP32 is then connected to an LCD display to indicate the access status to give a good visual feedback at the gate.

For authorized vehicles $(A = 1)$, an access command is transmitted from the processing unit to the ESP32 microcontroller via UDP. The received control signal $U(t)$ triggers servo motor rotation. The servo angle θ is defined by the pulse width modulation (PWM) duty cycle as shown in **Equation (8).**

$$\theta = k \times \text{PWM}_{duty} \qquad (8)$$

where k is a proportional constant. For unauthorized vehicles $(A = 0)$, the gate remains closed and an alert image is transmitted to security personnel via email.

Unauthorized Access Handling and Alert System

In case the vehicle number plate is not in the authorized database, the access will be refused and the gate will be closed. The captured image is stored in the system and automatically mailed as an email alert to the authorized security personnel. This real-time alert increases the surveillance and allows to respond quickly to possible security threats.

System Logging and Reliability

Any attempt of access made such as vehicle number, time and authorization status are also recorded to be used later and audited. The methodology allows secure operation, less human intervention, and enhanced industrial security as well as provide scalability in case of bigger deployment. All access attempts are logged with timestamps and authorization status. System accuracy η is evaluated using recognition performance metrics defined in **Equation (9).**

$$\eta = \frac{TP + TN}{TP + TN + FP + FN} \qquad (9)$$

where TP, TN, FP, and FN represent true positives, true negatives, false positives, and false negatives, respectively.

4. RESULT & DISCUSSION

This sub-chapter is a detailed discussion of the suggested contactless IoT-based smart doorbell and vehicle number plate detection system. The system was tested on the accuracy of number plate recognition, access decision and not only the communication latency but also the overall efficiency in operational performance under real time industrial environment. The experiments have been carried out to recreate realistic conditions such as change in lighting, type of vehicle, angled plate, and partially covered plate.

5. EXPERIMENTAL SETUP

The experimental design consisted of the high-resolution camera mounted on a gate at the industrial location, one processing unit that executes the machine learning-based number plate recognition algorithm, and an ESP32 microcontroller that drives a gate mechanism on a servo. The camera photographed cars coming to the gate and this was handled in real time. The test set used in the research consisted of authorized and unauthorized vehicles to compare the reliability of the recognition and access decision. Experiments were performed under various seasons of the day in order to overcome the changes in ambient light and shadows. This data was made up of 300 pictures of a total of 50 different cars, and there was a mix of a car, truck, and two-wheeler. ESP microcontroller was configured to accept access signals using UDP and to use the servo motor to operate the gates. The LCD monitor gave real-time information on access to the vehicle.

Number Plate Detection and Recognition Performance

The performance of number plate recognition was assessed in different conditions. The pre-processing, which involved the grayscale conversion, the Gaussian filtering, the contrast enhancement to enhance the system, enabled it to work well even when the light was low and the head had partial occlusion. **Table I** summarizes the recognition performance:

Number Plate Recognition Accuracy Under Different Conditions

Condition	Number of Samples	Correct Recognition	Accuracy (%)
Daylight	120	116	96.67
Low Light	80	74	92.50
Angled View	60	55	91.67
Partial Occlusion	40	36	90.00
Overall	300	281	93.67

The findings reveal that the system has a recognition accuracy of above 90 percent in all experimented situations which shows the strength of the machine learning-based model. Daylight conditions were the most accurate in recognition because of strong contrast and weak shadows. There was a little degradation in angled and partially occluded plates, which is not surprising in a realistic industry setting. However, the general rate of recognition of 93.67 proves the fact that the system can be used in real-life deployment.

Access Control Decision Analysis

Once recognized the system then authorizes by checking against a pre-registered vehicle database. The classification metrics that were used to assess the decision making capacity of the system included true positives (TP), true negatives (TN), false positives (FP) and false negatives (FN). **Table II** presents the access decision results:

Access Control Decision Results

Metric	Count	Observations
True Positives (Authorized Allowed)	145	Vehicles correctly granted access
True Negatives (Unauthorized Blocked)	130	Unauthorized vehicles correctly denied
False Positives	12	Rare instances of unauthorized vehicles allowed
False Negatives	13	Authorized vehicles occasionally denied

The false positives (4% of unauthorized attempts) are also low, meaning that the security is well enforced, whereas the false negatives (4.3% of authorized vehicles) can be explained either by bad visibility or extreme occlusion. These errors can be further reduced by constant enhancement of the dataset and algorithm training.

Communication Latency and Gate Response Time

UDP was chosen as the method of measuring the communication performance between the processing unit and ESP32 microcontroller due to its low-latency features. The total gate operation time is composed of three components: image processing time (T_{proc}), UDP transmission delay (T_{comm}), and servo motor actuation time (T_{servo}).

$$T_{total} = T_{proc} + T_{comm} + T_{servo}$$

The average time of these components is shown in figure 3. Processing time was at 700 ms, UDP transmission delay was 40ms, and servo motor actuation took about 400ms giving a total response time of about 1.14 seconds, which is comfortable in terms of industrial application.

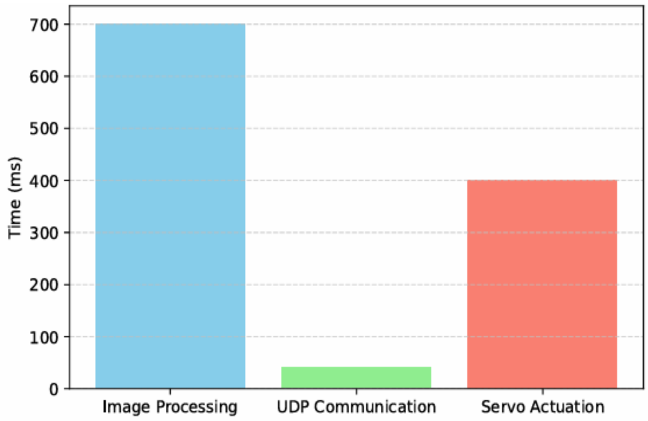

Figure 3.Average Gate Response Time Components

The bar chart is used to compare the three components with different trials. Processing time variations exist because of the variations in the complexity of the images and communication and actuation time was constant.

System Accuracy and Reliability Analysis

On the 300 test samples, the accuracy of the system was estimated at about 93.67, which are also similar to the number plate recognition results.

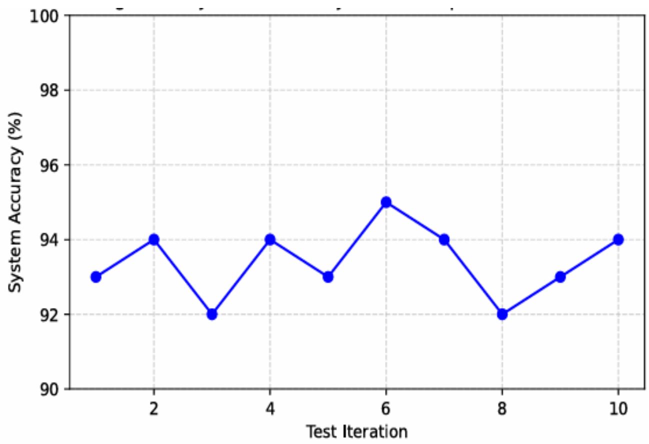

Figure 4 shows accuracy of the system when it was tested ten times. The line graph shows that all cycles have a steady accuracy of more than 92, and this means that the system has the potential to be reliable in the long-term performance in the industry.

6. DISCUSSION

The experimental assessment proves that the suggested contactless IoT-based system of smart doorbell and vehicle number plate detection is highly reliable and efficient in the industrial contexts. There were always more than 90 percent recognition rates of number plates in different lighting conditions, oblique angles, and biased obstructions, which shows the strength of the machine learning algorithm. There were very few false positives and false negatives and the access control decisions were very accurate hence ensuring that unauthorized vehicles were effectively prevented and that authorized vehicles made free entries. UDP communication allowed transmitting signals with low latency and the overall time of gate response was about 1.14 seconds, which is appropriate in real-time industrial applications. Also, the email notification system regarding the unauthorized cars increased the security control and enabled the timely response. All in all, the system minimizes human dependence, records access history, and offers a scalable and secure way to enter the industrial vehicles, which clearly has notable benefits over the traditional manual or RFID-based approaches to access control.

7. CONCLUSION

The paper has introduced a non-contact IoT-based smart doorbell and vehicle number plate recognition system that can automate the process of controlling access to the industrial vehicles and ensure better security and efficiency. The proposed solution will combine number plate recognition based on machine learning, IoT-enabled communications, and embedded gate automation to do away with manual intervention at the entry points of industries. It was experimentally shown that the system had an overall number plate recognition accuracy of 93.67 percent under a variety of operating conditions, such as changes in lighting conditions, viewing angles, and partial occlusions. The mechanism of access decision was highly reliable with low levels of false-positive and false-negative whereby the authorized vehicles were allowed entry whereas the unauthorized vehicles were effectively denied. One of the most important contributions of the work is the integration of the computer vision and the Internet of Things technology with a low-latency UDP communication framework. The gate control mechanism based on ESP32 allowed it to actuate quickly and thus the total gate response time was about 1.14 seconds, enough to meet the real-time industrial access needs. Security was also enhanced by the automated email notifications to unauthorized vehicles to ensure real-time monitoring and quick reaction has been made possible. The system also stores digital access logs which facilitates traceability and auditability in the industrial operations. The suggested system has great benefits compared to the traditional manual and RFID-based access control procedures as it decreases the dependency on manpower, ensures a low level of human errors, and offers a completely contactless functionality. Its scalable and modular design can be readily implemented in large industrial systems and can also be expanded in the future. Future research will aim to increase the accuracy of recognition in severe environmental conditions, adopt deep learning model to enhance robustness, add cloud-based access control and analytics, and adopt mobile and web-based dashboards to monitor and control remotely. The improvements will also add more intelligence, scalability, and applicability to the systems in smart industrial ecosystems..

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