

Design and Implementation of a Secure Autonomous Indoor Delivery Robot Using Deep Learning-Based Face Recognition

Malleshwari M.¹, Mamtha G.², Nisha R.³, Nandhini M.⁴

^{1,2,3}Student, ⁴Professor, Department of Electronics and Communication Engineering, P.S.V College of Engineering and Technology, Krishnagiri, India.

E-mail: ¹mmalleshwarimuniraj@gmail.com, ²mamthag1206@gmail.com, ³runisha2005@gmail.com,

⁴nandhini.abinaya@yahoo.com

Abstract

This paper discusses the development and implementation of an indoor delivery robot equipped with the face recognition facility through a deep learning-based architecture for authentic and safe delivery within smart indoor locations. This system will provide benefits in terms of enhanced security, automation, and efficiency for purposes like delivering items in hospitals, offices, laboratory areas, and smart indoor buildings. The face recognition facility will be implemented through a Deep Neural Network (DNN) approach for recognizing the user for verification. A robot platform is created through an ESP32 microcontroller connected to DC motors, motor driver, camera module, and ultrasonic sensors. The proposed robot will be able to move in designated areas inside the smart environment while detecting any possible obstruction in its way. Once the robot reaches the destination point, it will use the face recognition facility for authenticating the user before giving access to the package. Furthermore, communication over the Internet of Things (IoT) platform facilitates wireless monitoring and management. Experimental analysis indicates robust navigational skills and reliable obstacle detection.

Keywords: Autonomous Indoor Delivery Robot, Deep Learning, Face Recognition, Deep Neural Network (DNN), ESP32, Internet of Things (IoT), Secure Delivery, Smart Robotics.

1. Introduction

The evolution and implementation of technologies like automation, AI, and intelligent systems have led to great changes in the field of modern-day indoor deliveries [1]. The use of autonomous delivery vehicles is becoming more common in places such as hospitals, offices, labs, hotels, and smart buildings for the sake of improving efficiency and relieving the human operator from carrying out all the activities manually [2]. Traditional ways of performing indoor deliveries are dependent mainly on human labor, and this makes it harder to perform these tasks within a shorter amount of time, making them costly and insecure at the same time [3]. In some cases, where security matters a lot, like hospitals and corporate organizations, it becomes essential that whatever item being delivered is securely delivered to its final destination.

The latest breakthroughs in deep learning and computer vision technologies have allowed for the development of robust real-time face recognition methods that can reliably perform accurate identification in changing environmental situations [4]. The use of Deep Neural Networks (DNN) to identify faces has proven to be highly effective in identifying high-dimensional features that can be used in the authentication process. When applied to autonomous robotic delivery systems, such intelligent recognition methods can offer an efficient way to ensure safe delivery processes without any human input. Additionally, IoT-based technology will allow for monitoring and communicating within the robotic network infrastructure.

While there are many autonomous indoor delivery robots that have been developed over the past few years, most of the existing systems have concentrated more on the navigational capabilities and task execution process without having any efficient recipient identification methods. There are many traditional systems that rely on human-based verification processes and insecure delivery methods that expose them to various security vulnerabilities. Therefore, the development of an autonomous indoor delivery robot with efficient navigational and recipient verification capabilities is crucial.

In order to solve these problems, this research paper outlines the design and development of a security-enhanced autonomous indoor delivery robot that incorporates the use of an efficient face recognition system with the help of deep learning techniques. In this regard, a Deep Neural Network (DNN) is used to extract the features of a person's face for

authentication purposes. The central processing unit of the system uses an ESP32 microcontroller. The robotic delivery mechanism includes DC motors, motors controllers, and ultrasonic sensors that enable automatic navigation within an indoor environment along with obstacle detection capabilities. The user identity is validated using facial recognition before allowing access to the recipient and completion of the delivery. With the help of robotics, machine learning, and the Internet of Things (IoT), the proposed approach offers a secure and economical solution.

2. Related Works

Recent breakthroughs in robotic technology, AI, and IoT have been instrumental in the emergence of autonomous indoor delivery and security systems. Everingham et al. [1] pioneered the PASCAL Visual Object Classes (VOC) challenge that served as a critical benchmark for object detection and computer vision studies. Rahim et al. [2] developed a face recognition system using deep learning to ensure the security of the Internet of Home Things (IoHT). The potential of deep neural networks in biometric recognition systems was further validated by Lee et al. [3] when they designed a facial recognition system embedded within a security robot. Lee and Shih [4] also demonstrated their work on an indoor autonomous security robot equipped with surveillance and navigation capabilities.

Various research works have also addressed secure delivery and robotic authentication technologies. In their work, Yang et al. [5] put forward the concept of privacy-preserving robotic multi-factor authentication framework that facilitates secure automated deliveries, stressing upon the need for robust user authentication and data security in smart logistics operations. Similarly, Gaikwad et al. [6] created a facial detection and recognition system based on the Internet of Things technology, where embedded hardware along with facial authentication techniques were used to develop the system. On the other hand, Mathews and Sreeja [7] built a custom quarantine service mobile robot for contactless deliveries using deep learning and ROS framework.

Autonomous navigation and motion planning techniques have also garnered a lot of attention recently. For instance, Imad et al. [9] presented a novel architecture based on deep learning NMPC for local motion planning tasks in last-mile delivery robots. Cheng et al. [11] designed an innovative smart logistics prototype system to support unmanned delivery systems

using artificial intelligence techniques. Similarly, Damjanović et al. [12] provided a review article on various SLAM and machine learning methods used in indoor autonomous mobile robots. The study highlighted the significance of localization and mapping in intelligent navigation systems. Zhong et al. [14] designed an indoor autonomous robot kit using voice commands.

In the domain of embedded artificial intelligence and biometrics, Biglari and Tang [13] examined the various machine learning approaches used in embedded systems, where the authors explored architectures of sensors and strategies for implementing AI-based systems. Dhuzuki et al. [10] developed a deep learning-based system that recognizes gestures through MediaPipe in rehabilitation IoT settings. Additionally, Zayed et al. [15] designed an FPGA-accelerated deep learning approach to biometrics-based authentication applications. Despite the progress made in the area of autonomous robots, face recognition, and smart deliveries, most systems have been concentrated mainly on navigation or surveillance capabilities without considering any form of authentication process for the recipients. However, the proposed system utilizes autonomous indoor navigation, Internet of Things communications, and DNN-based face recognition capabilities in a single platform to guarantee secured package delivery services inside buildings.

3. Proposed Methodology

The suggested solution aims to offer the delivery method which will be based on robotics, face recognition using artificial intelligence techniques such as deep learning, and Internet of Things. In general, the process of work of the proposed solution involves three consecutive stages including face registration, autonomous navigation, and face verification followed by the delivery of the package. First of all, it should be noted that the main purpose of the proposed solution is to make sure that the delivered item will reach only the registered person. As for the process of face registration itself, the registered person uses a camera module for registering his face. In this case, the proposed solution uses face recognition technology which is built around DNN models from OpenCV.

This process involves the extraction of facial regions in the obtained video frames before encoding the face features (facial feature vectors). Matching is done using cosine similarity between the obtained facial feature vectors and the facial embeddings obtained in the database. This system facilitates real-time face verification at low computational cost, making

it ideal for embedded robotics applications. The faces obtained from the camera are recognized using a face recognition system that uses a deep neural network (DNN) to detect unique facial landmarks and high-dimensional feature vectors. The facial features extracted are then encoded and stored in a secure database for future authentication. For the purpose of delivering the item, the robot moves towards the designated location using DC motors that are controlled by L298 motor drivers and ESP32 microcontrollers.

Once the delivery robot reaches its destination point, the face verification module gets activated, and then the identity verification is performed by comparing the face features of the recipient with those recorded in the database. First, the camera module captures the facial image of the recipient, and then the DNN-based recognition algorithm verifies the face features against those stored in the database. In case of successful identification, the robot is authorized to deliver the package, but if there is no proper verification, the delivery process is denied, ensuring that the package will not be delivered to any unauthorized recipient.

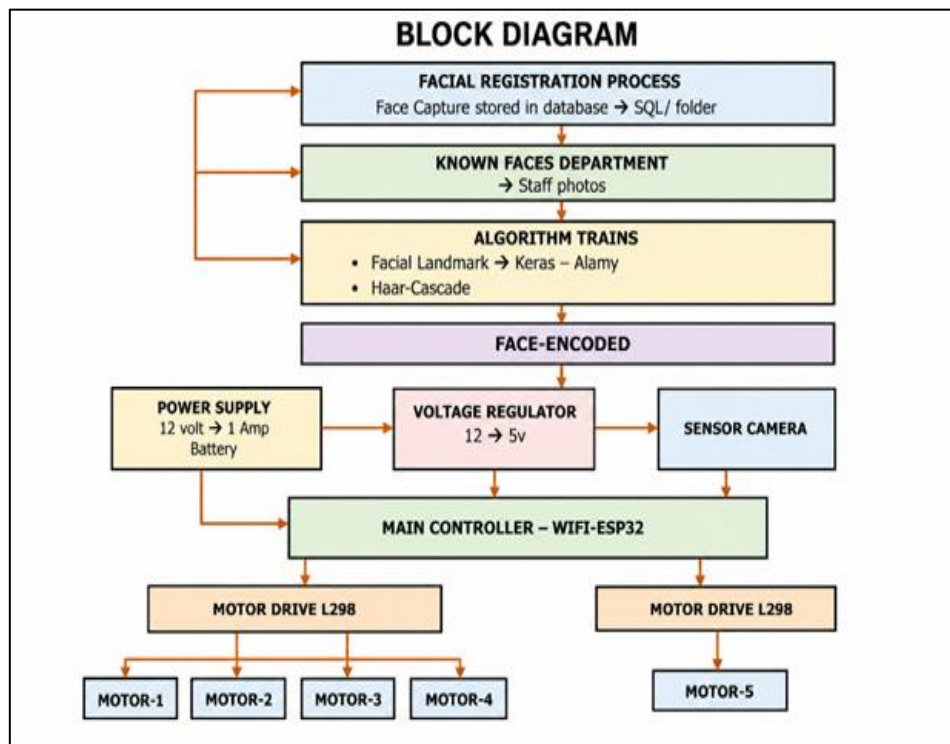


Figure 1. Block Diagram of the Proposed Secure Autonomous Indoor Delivery Robot

The block diagram of the proposed indoor delivery robot is illustrated in Figure 1. It comprises three main blocks, namely, facial registration and encoding, autonomous navigation, and secure face verification blocks. In the facial registration process, the facial images are taken

and saved in the database, from which the Deep Neural Network (DNN) algorithm extracts facial embeddings and encodes facial feature representation. The IoT communication protocol for the proposed model is implemented through the built-in Wi-Fi functionality in the ESP32 controller. The robot communicates with the monitoring interface via the HTTP protocol within a wireless local network. A light-weight web server running on the ESP32 provides real-time information regarding robot status, navigation, and authentication outcomes through a web browser-based interface. Currently, the system uses a storage-based approach to handle the user information and authentications locally, although the system can be modified in future iterations to use other IoT architectures, like Firebase or smart IoT based systems that use MQTT protocols. Here, the ESP32 microcontroller functions as the core processor and communication manager between the camera, motors, sensor modules, and navigation system.

The power source unit supplies controlled voltages to the ESP32 controller, camera module, and driver motors. The L298 driver motors provide controls to the several DC motors used in controlling robot motion and directionality. Moreover, there are sensors that detect obstacles in the environment and assist the robot in moving safely through indoor locations. Prior to dropping the package, the face recognition module obtains the live picture of the recipient and verifies against stored facial information. Dropping of the package takes place only after successfully recognizing the face of the recipient.

Phase 1: Face Registration

The face registration process will ensure that the faces of the authorized users are recorded into the face database. In this step, the camera will take several face pictures from various directions and lighting conditions. The face pictures will be analyzed through the use of Deep Neural Networks (DNN). During this analysis, the DNN will extract distinctive features of the face from the image and represent the extracted data using numbers, which will be stored in the database.

Phase 2: Autonomous Navigation

Autonomous Navigation allows the robot to navigate through indoor spaces efficiently, avoiding obstacles. The robot is guided via a navigation system that is connected to an ESP32 microcontroller that drives the motor using motor driver L298 and DC motors. Motor drivers help control the speed and direction of the motors to move according to pre-programmed delivery routes. Sensors continually scan the environment to identify any obstacles that could

lead to possible collisions. On detecting obstacles, the robot adjusts its path to continue its journey safely and efficiently.

Phase 3: Face Verification and Secure Delivery

Face verification process comes into action after the robot reaches the destination point. Facial image of the recipient will be captured by the camera module, and then the features extracted from the facial image will be matched against the facial data stored in the database. Real-time comparison of similar facial features is done using Deep Neural Network (DNN) based recognition process for the purpose of face verification. If the facial data matches the authorized user profile, access will be granted, and the process of delivering the package will take place. In the event of any mismatch, the delivery process will not occur due to the restriction in unauthorized access.

3.1 Hardware Components

Components for the proposed autonomous indoor delivery robot include various pieces of hardware responsible for navigation, face recognition, obstacle detection, and wireless communication (see Table 1). The ESP32 microcontroller serves as the control board for system coordination and Wi-Fi connection. The ESP32-CAM board takes care of capturing facial images required for user verification via the DNN-based face recognition system. Movement of the robot is managed by five DC motors driven by the L298 motor driver board. The ultrasonic sensors facilitate obstacle detection and indoor navigation. The LCD screen displays relevant information regarding the operation of the system and the process of face recognition. The power source subsystem features a 12V battery and a 7805m voltage regulator supplying stable 5V to the electronic modules.

Table 1. Hardware Component of Autonomous Delivery Robot

Component	Role
ESP32 Microcontroller	Main controller and Wi-Fi communication unit
ESP32-CAM Module	Captures facial images for recognition and authentication
L298 Motor Driver	Controls motor speed and direction
DC Motors (5)	Enables robot movement and navigation
Ultrasonic Sensor	Detects obstacles and measures distance

LCD Display	Displays system status and authentication messages
12V Battery	Main power supply for the robot
Voltage Regulator (7805)	Converts 12V supply to regulated 5V output
Chassis	Provides structural and mechanical support

3.2 Software Components

Designing the software architecture of the suggested autonomous indoor delivery robot is geared towards providing secure face recognition and efficient data processing capabilities in addition to controlling system operations. It is evident from Table 2 that the Deep Neural Network (DNN) is employed as the primary face recognition algorithm capable of identifying the faces of authorized users in real-time. The facial recognition operation involves the utilization of the DNN algorithm to analyze face images acquired through the use of the camera component and identify unique facial features used in verification. Additionally, face encoding algorithms are incorporated to convert facial features into numerical vectors referred to as facial embeddings.

Table 2. Software Component of Autonomous Delivery Robot

Component	Role
OpenCV DNN-Based Face Recognition Mode	Face detection and facial embedding extraction
Face Encoding Algorithm	Feature extraction
Database	Stores face data
Embedded C / Python	Control programming

Moreover, there is also an incorporated database component through which the coded information about the face of the registered user will be safely stored in order to facilitate future authentication. In the process of the package delivery, the captured real-time image of the face of the receiver is checked against the stored information from the database. The control and coordination of the whole robot are realized by means of Embedded C and Python programming languages. While Embedded C serves to control low-level processes inside the ESP32 microcontroller, including hardware interfacing and controlling the motors, the Python language serves to create face recognition algorithms, perform image processing tasks, and interact with the database. The detailed software components and their functions.

4. Results and Discussion

The developed secure autonomous indoor delivery robot has been tested using the lab-scale indoor experimental setup, which includes corridors, static obstacles, and different checkpoints for deliveries. The testing procedure emphasized the system's overall performance, which included autonomous navigation stability, facial identification response time, obstacle avoidance capability, wireless monitoring facility, and coordination among hardware devices. In particular, the ESP32 controller kept coordinating the navigation system, ultrasonic sensor module, and facial recognition system throughout the entire process of delivery. In the course of the experiment, the robot demonstrated its ability to navigate predetermined indoor routes while simultaneously avoiding nearby obstacles sensed by the ultrasonic sensor. Furthermore, the web-based monitoring user interface provided constant real-time data about the movement of the robots, authentication, and delivery status via the wireless IoT communication structure. The IoT communication architecture used was capable of maintaining a wireless interaction process between the robot and the web-based monitoring interface. The ESP32-based HTTP communication architecture effectively conveyed the authentication status, navigation, and monitoring data of the system with very little communication latency indoors.

The face recognition module based on DNN worked efficiently and reliably throughout the user authentication in real-time mode. In the system, the facial recognition process used encoded facial embeddings with high-dimensional facial feature extraction to improve identification and reduce false recognition. The recognition technology showed stable operation both under normal indoor illumination conditions and despite slight variations in the position of the face and the angles at which the face was viewed. The face identification procedure took place quickly in real time, thereby allowing for timely package delivery authentication.

In the case of autonomous navigation, the autonomous navigation system proved itself to be reliable in indoor navigation and obstacle detection. The ESP32 controller successfully operated the DC motors with the help of L298 motor driver circuitry, thus ensuring smooth motion in the required direction. Meanwhile, ultrasonic sensors were responsible for detecting any obstacles nearby and helping the robot move around them successfully. Robotic equipment successfully worked without experiencing any navigational and communication problems during continuous operation. Along with robot control and facial recognition functionality, our

solution offers a web-based interface for controlling the system. Users will be able to observe the robot performance, delivery process, facial recognition results, and other navigation updates using a wireless Internet connection. The incorporation of the web-based user interface greatly enhances the accessibility, remote monitoring, and interaction capabilities of the intelligent indoor system.

In addition to that, the hardware implementation outcomes successfully established that the integration of all hardware components, such as the ESP32 microcontroller, camera sensor, motor control circuits, DC motors, voltage control circuit, battery pack, and robot chassis was successful. The images of the hardware configuration clearly show the implementation of the suggested autonomous delivery system and its ability to operate in real-time. Thus, the experimental findings indicate that the incorporation of AI techniques, embedded systems technology, IoT communication, and web technologies offers a reliable solution for future autonomous indoor delivery applications.

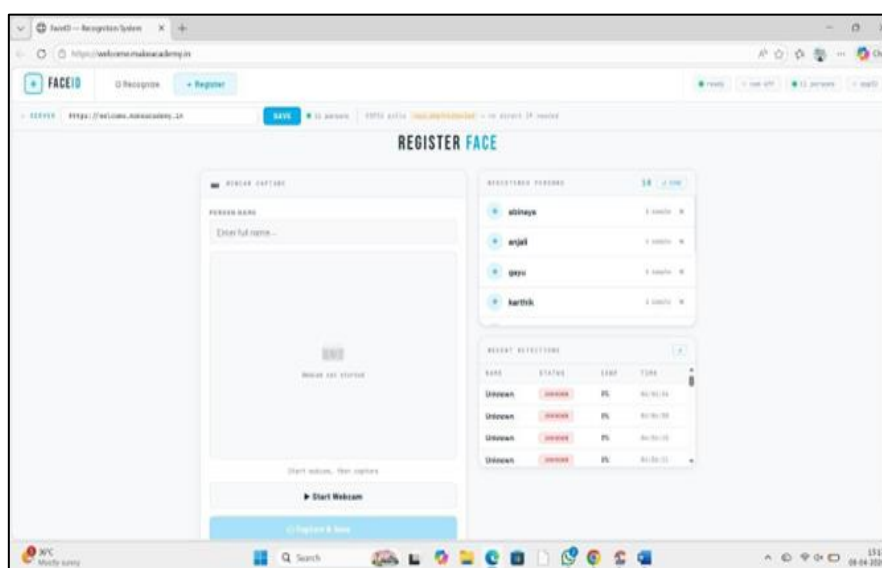


Figure 2. Web Page of Face Recognition for Register

Figure 2 shows the designed web-based interface of the secure autonomous indoor delivery robot. The web interface serves as an interactive platform to register the authorized users, manage the facial data, and monitor the activities of the system through wireless networking. In the registration phase, facial images of the users are captured via the incorporated camera module using DNN-based face recognition system to obtain facial embeddings to authenticate the users. The web-based interface is designed to show information related to user details, detection logs, recognition status, confidence, and timestamps. The

incorporation of the designed web-based monitoring system with the ESP32-based robot improves system efficiency.

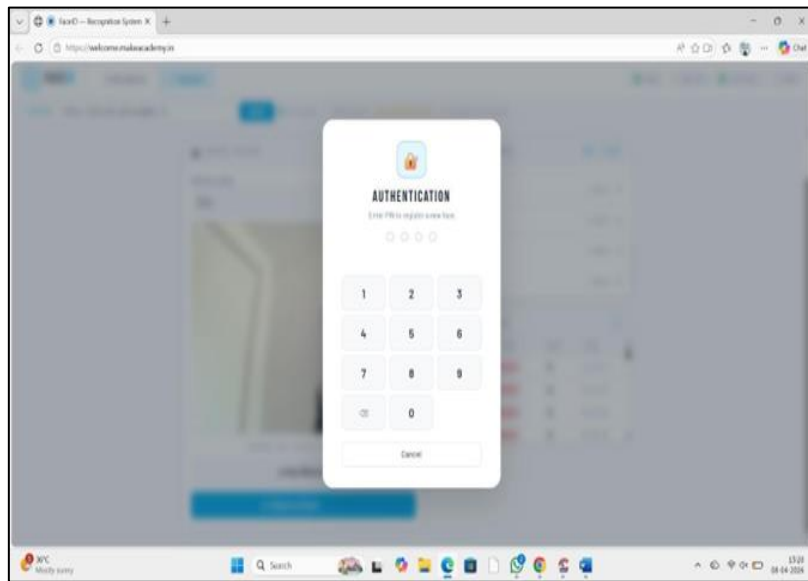


Figure 3. Web Page of Face Recognition for Registering with Pin Code

Figure 3 demonstrates the authentication interface implemented in the designed secure autonomous indoor delivery robot system. The purpose of the authentication module is to offer enhanced security for the users through the need to provide a secure access code to log in and access the functions of the system. The authentication interface communicates with the online monitoring interface and operates in conjunction with the Deep Neural Network (DNN) face recognition technique. The verification process using a keypad enhances security, control access to delivery services, and increases the effectiveness of the designed autonomous delivery system.

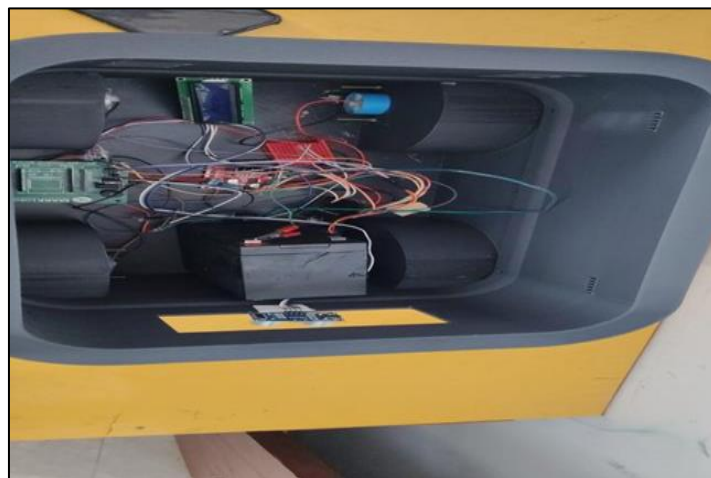


Figure 4. Hardware Prototype of the Secure Autonomous Indoor Delivery Robot

As shown in Figure 4, the hardware setup of the suggested secure autonomous indoor delivery robot system is placed in a compact housing unit. The system contains a microcontroller unit, relay controller, power source, LCD screen, sensor connections, and communication modules that are interlinked using embedded circuits. The proposed system can be used for autonomous navigation, security, and monitoring. Deep learning-based face recognition technology is implemented in the system to ensure only the authenticated users receive packages, thus improving security and efficiency in indoor conditions.



Figure 5. Ultrasonic Sensor Module Integrated into the Autonomous Delivery Robot for Obstacle Detection

As indicated in Figure 5, this figure represents the ultrasonic sensor module that is mounted on the front part of the indoor autonomous delivery robot. The sensor module is used to detect obstacles and measure the distance in real-time, thus allowing the robot to safely navigate indoors. Through the use of the sensor module to detect nearby objects, the robot can successfully avoid collision and improve its autonomous movement.

4.1 Limitations

Though the design of the secure and autonomous indoor delivery robot performs satisfactorily with respect to face recognition and autonomous navigation capabilities, there are still some limitations observed in the current design of the robot. The face recognition system using DNN is susceptible to lighting conditions that impact the facial image quality, hence affecting the face recognition capability of the system. Further, the navigation system has been

created based on the assumption that navigation will be done indoors on a single floor only and not multiple floors involving elevator operations. The current design of the robot is lacking any form of sophisticated liveness detection systems, hence making it open to face spoof attacks using photographs and digitally manipulated images. From an implementation point of view, integrating the embedded controller hardware with the deep learning system for face authentication increased the degree of automation of the system. Some of the above limitations can be considered for future research and include incorporation of adaptive lighting systems, multi-level intelligent navigation systems, and anti-spoofing algorithms into the framework.

5. Conclusion and Future Work

The suggested robot for secure autonomous indoor package deliveries can successfully integrate robotics, artificial intelligence, embedded systems, and Internet-of-Things technologies to enable safe indoor delivery operations. The robot is able to perform its task of indoor delivery using autonomous navigation and DNN-based face recognition in order to deliver only to authorized persons. The integration of the ESP32 microcontroller, camera module, motor drivers, and the web application allowed the robot to be safely controlled, recognize faces of users in real time, and interact efficiently with them. The experimental testing proved successful navigation, face recognition, and obstacle avoidance of the robot in indoor conditions. Moreover, compared with traditional indoor delivery methods, the proposed methodology offers superior authentication capabilities, better automation, and scalability in terms of system performance. Despite the limitations of the present solution that is constrained only to floor-level navigation and without liveness detection features, future improvements could be made such that the system will support autonomous navigation on multiple floors, cloud-connected database, anti-spoofing techniques, artificial intelligence-assisted navigation path selection, and more sophisticated SLAM capabilities.

References

- [1] Everingham, Mark, Luc Van Gool, Christopher KI Williams, John Winn, and Andrew Zisserman. "The Pascal Visual Object Classes (Voc) Challenge." *International journal of computer vision* 2010, vol. 88, no. 2: 303-338.

- [2] Rahim, Asif, Yanru Zhong, and Tariq Ahmad. "A Deep Learning-Based Intelligent Face Recognition Method in the Internet of Home Things for Security Applications." *Journal of Hunan University Natural Sciences* 2022, vol. 49, no. 10: 39-52.
- [3] Lee, Min-Fan Ricky, Yun-Min Huang, Jia-Yang Sun, Xue-Qin Chen, and Ting-Fu Huang. "Deep Learning Based Face Recognition for Security Robot." In 2022 18th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (MESA), 1-6.
- [4] Lee, Min-Fan Ricky, and Zhih-Shun Shih. "Autonomous Surveillance for an Indoor Security Robot." *Processes* 2022, vol. 10, no. 11: 2175.
- [5] Yang, Yang, Prosanta Gope, Aryan Pasikhani, and Biplab Sikdar. "Privacy-Preserving Robotic-Based Multi-Factor Authentication Scheme for Secure Automated Delivery System." *IEEE Transactions on Information Forensics and Security* 2025, vol. 20, 11860-11875.
- [6] Gaikwad, Vijay, Devanshu Rathi, Vansh Rahangdale, Rahul Pandita, Kashish Rahate, and Rajendra Singh Rajpurohit. "Design and Implementation of IoT Based Face Detection and Recognition." *Computing & Intelligent Systems* 2024, 923-933.
- [7] Mathews, Sanjuna Mariam, Sreeja. "Design and Implementation of Custom Built Quarantine Service Mobile Robot Using Deep Learning and ROS." *Stochastic Modeling & Applications* 2022, vol. 26, no. 3: 315-331.
- [8] Narayan, Devika, B. S. Devika, and K. L. Nisha. "Design and Simulation of an Autonomous Medicine-Serving Robot with Deep Learning-Based Patient Recognition Using ROS." In 2026 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE), 1-7.
- [9] Imad, Muhammad, Oualid Doukhi, Deok Jin Lee, Ji Chul Kim, and Yeong Jae Kim. "Deep Learning-Based NMPC for Local Motion Planning of Last-Mile Delivery Robot." *Sensors* 2022, vol. 22, no. 21: 8101.
- [10] Dhuzuki, Nurul Hanis Mohd, Ahmad Anwar Zainuddin, Nur Anis Sofea Kamarul Zaman, Alin Nur Maisarah Ahmad Razmi, Wonderful Shammah Kaitane, Asmarani Ahmad Puzi, Mohd Naquiuddin Johar et al. "Design and Implementation of a Deep

- Learning-Based Hand Gesture Recognition System for Rehabilitation Internet-of-Things (RIoT) Environments Using MediaPipe." *IJUM Engineering Journal* 2025, vol. 26, no. 1: 353-372.
- [11] Cheng, I-Lok, Ching-Hwa Cheng, and Don-Gey Liu. "A Learnable Unmanned Smart Logistics Prototype System Design and Implementation." In 2019 IEEE International Conference on Artificial Intelligence Circuits and Systems (AICAS), 221-224.
- [12] Damjanović, Davor, Petar Biočić, Stjepan Praljačić, Dorian Činčurak, and Josip Balen. "A Comprehensive Survey on SLAM and Machine Learning Approaches for Indoor Autonomous Navigation of Mobile Robots." *Machine vision and applications* 2025, vol. 36, no. 3: 55.
- [13] Biglari, Amin, and Wei Tang. "A Review of Embedded Machine Learning Based on Hardware, Application, and Sensing Scheme." *Sensors* 2023, vol. 23, no. 4: 2131.
- [14] Zhong, Ren, Zhaofeng Tian, Qiren Wang, Mingyu Guo, and Weisong Shi. "Design and Implementation of a Voice Controlled Indoor Autonomous Robot Kit." In 2025 IEEE 3rd International Conference on Mobility, Operations, Services and Technologies (MOST), 89-99.
- [15] Zayed, Nourhan, Nahed Tawfik, Mervat MA Mahmoud, Ahmed Fawzy, Young-Im Cho, and Mohamed S. Abdallah. "Accelerating Deep Learning-Based Morphological Biometric Recognition with Field-Programmable Gate Arrays." *AI* 2025, vol. 6, no. 1: 8.