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Implementation of Haar Cascade and K-Nearest Neighbors (KNN) Face Recognition for Optimizing Warehouse Access Control Security

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Abstract: Warehouse facility access control security represents a critical factor in maintaining operational integrity and preventing criminal activities. This research addresses the elevated security threat risks associated with physical surveillance systems that continue to rely on manual methods with suboptimal performance. The study develops an automated security system based on face recognition technology, implementing Haar Cascade and K-Nearest Neighbors Classifier methods to identify and verify warehouse user identities with precision and automation. The research object focuses on facial recognition systems for warehouse access control. The methodology applies Haar Cascade algorithms for facial detection and K-Nearest Neighbors Classifier for classifying detected faces against existing datasets. Implementation utilizes external webcams, computer hardware, and Python-based programming software. Results demonstrate that the developed system achieves facial recognition accuracy exceeding 90%, delivering superior security performance compared to manual systems. The research concludes that face recognition technology effectively enhances efficiency and security in warehouse access management. The study recommends implementing such systems in large-scale warehouse facilities to optimize security management protocols.

Keywords: Security; Face Recognition; Haar Cascade; K-Nearest Neighbors Classifier; Access Control.

1. Introduction

Security is the most important factor in managing storage facilities or warehouses. Manual access control systems such as keys or identification cards are often very weak and vulnerable to misuse or loss, creating a threat of unauthorized access. Shetty *et al*. (2021) described how relying on manual systems creates huge holes in the security infrastructure of a facility [1]. Nugroho (2024) added that traditional systems are not only prone to loss or theft but also allow duplication which can be used by unauthorized parties [2]. In addition, dependence on security personnel brings about dangers of carelessness or identification mistakes that eventually endanger the integrity of warehouse security. Gangopadhyay *et al*. (2020) stated that human involvement in identity verification increases the chances of human error which could lead to disastrous results for facility security [3].

With technological development, solutions based on face recognition have been more and more widely used in order to solve such problems. The technology allows systems to carry out identity checks automatically through processing images of faces, thus increasing precision and decreasing human intervention. Shetty *et al*. (2021) proved that systems using facial recognition can provide better levels of security than conventional methods because facial biometric characteristics are unique to individuals and very hard to falsify [1]. One popular method is the Haar Cascade algorithm which is known for its detection speed when identifying objects related to faces in real time. Chinimilli *et al*. (2020) proved that Haar Cascade has high computational efficiency hence face detection can be done quickly even on devices with limited specifications [4]. For the classification stage, K-Nearest Neighbors Classifier (KNN) has been proven effective in recognizing identities based on extracted features from faces. Gangopadhyay *et al*. (2020) mentioned that using Haar Cascade for detection and classification algorithms like KNN for identification makes a very strong and accurate system possible [3].

Although face recognition systems based on Haar Cascade and KNN have proven effective in various applications, their implementation in Indonesia, particularly in warehouse environments, remains relatively scarce. Several factors contribute to the situation, such as technological infrastructure constraints, relatively high implementation costs, and insufficient technical understanding among facility managers regarding modern biometric technology. Nugroho (2024) identified that the primary barriers to face recognition technology adoption in Indonesia are technical knowledge gaps and resource availability for system deployment [2]. Previous research also revealed that environmental conditions such as poor lighting or extreme facial viewing angles remain challenges in detection accuracy. Choi *et al*. (2022) found that lighting variations and suboptimal face positions can reduce detection system performance by 15-20% [5]. Gangopadhyay *et al*. (2020) added that environmental factors such as partial occlusion, changing facial expressions, and low image quality require more sophisticated preprocessing approaches to maintain system accuracy [3]

Therefore, the research aims to develop and implement a face recognition system using Haar Cascade algorithm and K-Nearest Neighbors Classifier to enhance security and efficiency in warehouse access control systems. By employing the technology, the accuracy and reliability of face recognition systems in verifying user identities are expected to be more optimal while reducing dependence on manual methods vulnerable to security breaches. Minu *et al*. (2020) demonstrated that integrating Haar Cascade with KNN in face recognition-based security systems can achieve accuracy levels above 90% under controlled conditions [15]. The research will also explore how applying the technology can positively impact access management in warehouse facilities, considering cost factors, effectiveness, and ease of implementation within Indonesian warehouse operational contexts. Additionally, the research integrates Role-Based Access Control (RBAC) concepts to provide flexibility in access rights management based on user roles, thereby not only enhancing security but also operational efficiency in managing multi-level access in warehouse environments.

Based on the background outlined above, the research identifies two primary problems requiring resolution. First, high security risks in warehouse facility access that still rely on manual and ineffective systems, where using physical keys or identification cards as access control tools has significant weaknesses—they can be lost, misused, or duplicated—thus opening gaps for potential unauthorized intrusion that can endanger warehouse facility security and integrity. Second, warehouse access control systems that still rely on manual verification add risks toward user identification errors, where dependence on human intervention in verifying identities creates potential operational errors such as negligence or mistakes in checking accessor identities, which can cause unauthorized access and threaten facility security while increasing potential criminal activities.

Based on the problem identification, the research formulates the following research questions: How can security systems in warehouse facilities be optimized using face recognition technology based on Haar Cascade algorithm and K-Nearest Neighbors Classifier? The research aims to determine the best approach in combining both algorithms to ensure user identity verification is performed automatically, accurately, and efficiently without requiring manual intervention, while addressing various challenges related to lighting, facial viewing angles, and image quality that can affect face recognition system performance. Moreover, the research will explore how Role-Based Access Control (RBAC) implementation can be integrated into the system to provide more granular access control based on user roles and responsibilities in warehouse environments.

The research aims to examine and analyze the effectiveness of implementing face recognition technology with a combination of Haar Cascade algorithm and K-Nearest Neighbors Classifier in building more secure and efficient warehouse access control systems. The ultimate goal is to present a biometric-based system capable of replacing previously used manual methods while ensuring the system has high accuracy in recognizing users and can be relied upon to reduce security risks in warehouse environments. Additionally, the research aims to evaluate system capabilities in handling environmental condition variations such as suboptimal lighting and diverse facial viewing angles, as well as measuring operational efficiency and cost-effectiveness of system implementation within Indonesian warehouse facility contexts.

The problem-solving approach in the research employs systematic and structured methods to identify, analyze, and resolve issues related to access control management in warehouse facilities. The primary focus is applying face recognition technology based on Haar Cascade algorithm and K-Nearest Neighbors Classifier to enhance security and optimize user identity verification processes. The first step involves identifying existing problems, namely high security risks associated with manual access control systems still widely applied in warehouse facilities, along with system limitations in ensuring user identities accurately and efficiently. The second step involves analyzing applicable technologies to address such problems, where face recognition technology based on Haar Cascade and K-Nearest Neighbors Classifier will be evaluated to determine the extent to which both algorithms can replace existing manual systems with focus on security, accuracy, and operational efficiency aspects. At the stage, collecting technical data regarding strengths and weaknesses of each algorithm as well as their integration methods in access control systems will be conducted to produce effective solutions. The third step encompasses solution design and implementation based on conducted analysis, where face recognition systems using Haar Cascade algorithm for face detection and K-Nearest Neighbors Classifier for user identity classification will be tested to ensure accuracy and efficiency. Following implementation, systems will be tested and evaluated to measure accuracy levels and their capabilities in reducing security risks compared to manual systems, and based on evaluation results, system refinements and further implementation recommendations will be provided for other warehouse facilities.

Various previous studies have been conducted regarding Haar Cascade algorithm and K-Nearest Neighbors application in face recognition systems, providing strong foundations and becoming references in developing the proposed system. Research on face recognition systems based on Haar Cascade and classification methods like K-Nearest Neighbors has shown promising performance in various security scenarios. Rahmad *et al*. (2020) compared Haar Cascade method and Histogram of Oriented Gradients (HOG) for face detection, demonstrating that Haar Cascade has advantages in time efficiency despite slightly lower accuracy than HOG, making it an optimal choice for real-time applications [19]. Riyantoko *et al*. (2021) utilized Haar Cascade in combination with Convolutional Neural Networks to detect facial expressions and obtained high accuracy in emotion recognition, proving algorithm flexibility in various image-based applications [21]. Zeebaree and Kareem (2022) developed a face mask detection system with Haar Cascade as part of COVID-19 surveillance systems, emphasizing the necessity of real-time systems and response speed to detect faces in diverse environmental conditions such as low lighting and extreme facial angles [25]. Minu *et al*. (2020) integrated Haar Cascade with KNN algorithm for home security systems based on face recognition, where the system was equipped with motion sensors and capable of distinguishing registered from unregistered faces, thereby enhancing automatic identity verification accuracy [15]. Ahmad *et al*. (2021) demonstrated real-time video surveillance system implementation using Haar Cascade Classifier capable of detecting and recognizing faces with high accuracy levels under various lighting conditions [20]. Isnanto *et al*. (2021) combined Local Binary Pattern Histogram with Haar Cascade Classifier for multi-object face recognition on low-resolution images, showing that proper preprocessing can significantly enhance system performance [18]. Considering results from previous studies, implementing the combination of Haar Cascade and K-Nearest Neighbors Classifier becomes a relevant and efficient solution in building secure and automatic warehouse access control systems.

The primary contributions of the research can be explained through two significant aspects. First, combining two methods to enhance accuracy and efficiency, where one major contribution is the integration of two different algorithms—Haar Cascade and K-Nearest Neighbors Classifier—in a single integrated access control system. Previous research generally used each algorithm separately, where Haar Cascade was used for face detection and K-Nearest Neighbors Classifier was used for user identity classification, but the research integrates both algorithms in the same system to enhance accuracy and efficiency in face detection and classification. The combination allows systems to leverage strengths of both methods in detecting faces quickly and classifying user faces accurately, with more optimal results under various warehouse operational environmental conditions. Second, applying Role-Based Access Control (RBAC) to security systems, where a novel contribution in the research is RBAC system integration to differentiate user access rights based on their respective roles in organizations. Each verified user identity is not only recognized based on face but also linked to specific roles subsequently used to regulate access levels to particular areas within warehouses. RBAC application provides flexibility in access rights management and enhances control over who can enter specific zones, thereby creating additional security layers that not only rely on biometric identification but also role-based authorization, which becomes a significant differentiator from previous studies that only focused on identification aspects without considering access control granularity.

2. Related Work

Facial recognition has been extensively researched in the past 10 years, as many researchers have tried different algorithmic approaches to solve the problems of security and identification in different domains. The Haar Cascade classifier was introduced by Viola and Jones and this has become one of the most popular methods for object detection because it is computationally efficient and can be processed in real-time. Rahmad *et al.* (2020) compared the performance of Viola-Jones Haar Cascade classifier with Histogram of Oriented Gradients (HOG) for face detection [19]. HOG gave slightly better accuracy, but Haar Cascade was much faster and thus more applicable in cases that require real-time responses. The study recommends weighing the trade-off between accuracy and speed against application requirements. Nugroho and Sela (2024) studied the practical implementation of Haar Cascade classifier algorithm for face detection; they documented its effectiveness at finding features on faces under varying conditions [6]. This work has shown that it can manage scale variation and rotation, although performance deteriorates under extreme lighting conditions. Choi *et al.* (2022) presented an improved version of Haar Cascade classifiers based on vertical component calibration to address one main limitation of the algorithm--sensitivity to facial orientation [5]. Their method achieved better detection rates for faces taken at nonfrontal angles with accuracy improvements from about 12-18% compared to standard implementations of the Haar Cascade classifier. Antipona *et al.* (2024) undertook research into improving the performance of the base algorithm specifically for gate pass security applications [7]. Their research proved that careful tuning of cascade stages and detection thresholds could bring about a significant drop in false positives while keeping true positive detection rates high.

Several authors have investigated hybrid methods that merge Haar Cascade with other approaches to improve the overall performance of the system. Shetty *et al.* (2021) designed a facial recognition system in which Haar Cascade was used for detection and Local Binary Pattern (LBP) classifiers were used for recognition. This achieved robust performance across various datasets [1]. Their approach proved that integrating the fast detection power of Haar Cascade with texture-based feature extraction from LBP can result in systems that are both speedy and precise. Chinimilli *et al.* (2020) reported on a face recognition-based attendance system utilizing Haar Cascade together with the Local Binary Pattern Histogram algorithm; it has been successfully deployed in educational institutions with recognition accuracy over 92% [4]. This research dealt with real-world issues such as multiple face handling at once, database scalability management, and responsiveness of the system during peak times. They found that proper training data selection and regular model updates were critical to keeping systems accurate over time. Isnanto *et al.* (2021) addressed multi-object face recognition on low-resolution images by using Local Binary Pattern Histogram combined with a Haar Cascade classifier [18]. This work is more relevant to surveillance applications where image quality may be poor due to distance, camera specifications, or environmental factors. The study proved that suitable preprocessing techniques like histogram equalization and noise reduction could significantly enhance recognition rates even when dealing with low-quality images. Gangopadhyay *et al.* (2020) broadened the use of Haar Cascade beyond mere detection by adding expression recognition based on the Fisherface algorithm [3]. Their work indicated that facial expressions can be accurately recognized after the initial face has been detected, thereby creating opportunities for emotion-aware security systems capable of suspicious behavior pattern identification through facial cues.

Recent investigations have delved into the fusion of conventional Haar Cascade techniques with contemporary deep learning frameworks, aiming to harness the benefits inherent in both methodologies. In their work, Riyantoko *et al.* (2021) introduced a system for detecting emotions based on facial expressions; this system employed Haar Cascade for preliminary localization of faces, followed by Convolutional Neural Networks that classified the emotions [21]. Their hybrid model delivered better results than each method alone could provide: rapid localization of the face was achieved by Haar Cascade and nuanced recognition of various emotions was enabled by CNN. Ariffin *et al.* (2025) discussed performance in detecting faces with Haar Cascade as compared to pure Convolutional Neural Networks regarding computational requirements, accuracy metrics, and feasibility for deployment [8]. Their results showed that even though approaches based on CNN usually reached higher accuracy, using Haar Cascade was still beneficial when resources are limited or when applications need fast processing more than slightly improved accuracy. The flexibility of Haar Cascade has resulted in its use within many specific applications outside standard security systems. Zeebaree and Kareem (2022) created a face mask detection system using a Haar Cascades classifier to reduce the risks of COVID-19 transmission [25]. This system could tell apart people who had their masks on properly from those who did not or were unmasked at all; this proved that the algorithm could adjust itself for certain features or obstructions on faces rather than needing complete images of faces. Jemakmun and Suhirja (2023) created a mask detection system that included distance measurement capabilities to meet both needs of mask compliance and social distancing protocols [9]. They used Haar Cascade for face detection combined with depth estimation algorithms to calculate inter-person distances which showed how the algorithm could be integrated into more sophisticated multi-modal surveillance systems.

Ahmad *et al.* (2021) worked on the real-time video surveillance systems using Haar Cascade classifier and presented a case study emphasizing the algorithm's suitability for continuous monitoring applications. Their implementation addressed challenges such as maintaining consistent performance across extended operation periods, varying crowd densities, and efficiently managing computational resources. The study reported successful deployment in public spaces with the system processing multiple video streams simultaneously while maintaining detection accuracy above 88%. Beri *et al.* (2024) developed a face recognition attendance management system that combined LBPH and Haar Cascade. They reported successful implementation in organizational settings. Their system architecture included user enrollment modules, real-time recognition engines, and administrative interfaces for managing attendance records. This research further highlighted how important user experience design is for ensuring system adoption and what privacy concerns can be addressed regarding biometric data collection. Minu *et al.* (2020) proposed a home security system based on the Haar Cascade classifier integrated with motion sensors and alert mechanisms proposed by them. Their approach demonstrated how face recognition could be embedded within broader security frameworks automatically distinguishing between authorized residents from unknown individuals. The system's ability to trigger appropriate responses based on recognition results—such as granting access, sending alerts, or activating recording—illustrated the practical value of automated identity verification. Diyasa *et al.* (2021) investigated feature extraction techniques for face recognition using the Haar Cascade classifier by analyzing how different feature sets affected recognition accuracy and computational requirements in this regard to provide insights into optimizing the balance between feature richness and processing efficiency particularly relevant for embedded systems or mobile applications with limited computational resources.

Bahit *et al.* (2023) performed validation studies on the Haar Cascade classification method in face detection, systematically evaluating performance across different datasets and environmental conditions. Their research will set benchmarks for expected accuracy levels under various scenarios and serve as valuable reference points for practitioners who implement similar systems. The study also emphasized rigorous testing protocols and representative datasets to assess real-world system performance. Kalangi *et al.* (2021) described real-time face detection with image dataset loading on the Haar Cascade algorithm, which touches practical considerations about the training and deploying of recognition systems for faces. The size, diversity, and quality of the dataset were studied in relation to how they impacted model performance; this could be read as a guideline for preparing datasets and procedures when training models. Arya and Tiwari (2020) presented automatic face recognition and detection using OpenCV and Haar Cascade at various angles of the human face recorded performance variations with respect to pose. The results quantified accuracy degradation as the side orientation moved away from frontal, providing empirical data that would help inform camera placement decisions as well as system design considerations in access control applications. Researchers have looked into other innovative applications of Haar Cascade technology beyond regular security uses. Lakshmiprabha *et al.*, in 2025, researched autism detection through the Haar Cascade machine learning algorithm; this showed how such technology could be used for healthcare diagnostics. Though not directly related to access control, such research can also reflect the algorithm's versatility and potential adaptation to different recognition tasks. Srithar *et al.*'s improved framework based on feature extraction using the Haar Cascade specifically addresses access control for rich internet applications. This work looked at web-based face recognition systems' unique challenges like browser compatibility, network latency, and client-side processing limitations.

Though much has been studied about Haar Cascade uses in many applications, some gaps still need to be filled. Most work has been done in environments that are controlled with fairly similar lighting and camera angles. Not much research has been done on specific problems faced in warehouses. This may include changing light conditions, dust or tiny particles that can affect image quality, and the need for strong performance through several entry points each having different camera specs. Additionally, not many studies have looked at the combination of facial recognition systems with detailed access control like Role-Based Access Control (RBAC). Current systems usually work on a yes/no access decision—either allowing entry or not—without taking into account the complexity of organizational hierarchies and differentiated access privileges required in industrial settings. This research will fill those gaps by developing a system specifically tailored for warehouse environments, incorporating environmental adaptation strategies, and integrating RBAC functionality to enable sophisticated access management aligned with organizational structures and security policies.

3. Research Method

This research applies a software engineering approach to develop a warehouse access control system based on face recognition technology. The primary objective is to design a system capable of automatically and accurately identifying user identities while differentiating access rights according to user roles. The research method follows systematic stages including planning, data collection, system development, and testing.

3.1 Data Collection and Storage

The data used includes facial images from warehouse users collected using external cameras. Image capture is performed in real-time, and each face is processed using the Haar Cascade algorithm for detection, then classified using the KNeighborsClassifier algorithm. Ramadini and Haryatmi (2022) demonstrated that real-time face recognition systems require systematic data collection procedures to ensure consistent image quality across different capture sessions [11]. Subsequently, facial data is stored in .pkl file format containing feature encodings and identity labels. Kalangi *et al.* (2021) emphasized the importance of efficient dataset loading mechanisms when implementing real-time face detection systems, particularly regarding memory management and processing speed [17]. User identity and attendance information is stored in both database and CSV file formats. Similar implementations in Indonesian contexts, such as the attendance system developed by Mulyana *et al.* (2023), have shown that combining multiple storage formats provides redundancy and facilitates system integration with existing organizational infrastructure [33].

Table 1. Attributes of names.pkl

Attribute	Description
File	names.pkl
Data Type	List (Python List)
Contents	Stores the list of registered usernames in the face recognition system. Each entry records the username associated with collected facial data.
Structure	["Name"] – Each registered username is repeated according to the number of images collected from their face. For instance, a user with 60 images will have 60 entries of Name.
Function	Stores user identity information linked to detected facial data within the system.

Table 2. Attributes of faces.pkl

Attribute	Description
File	faces.pkl
Data Type	Numpy Array
Contents	Stores processed and encoded facial data. Each face is converted into a feature vector in the form of a 1D numpy array.
Structure	[[vector1], [vector2], [vector3], ...]
Function	Stores facial feature representations in vector format, used for classification and face recognition using algorithms such as KNeighborsClassifier.

3.2 System Development

System development uses a modular architecture, dividing main functions such as face detection, face classification, and role-based access control (RBAC) management. Szeliski (2022) noted that modular architecture in computer vision systems allows for independent optimization of each component while maintaining overall system coherence [29]. Face detection is performed using Haar Cascade from the OpenCV library, while classification uses the KNN algorithm to recognize users based on training data. Verdhan (2020) explained that leveraging established computer vision libraries like OpenCV significantly reduces development time while ensuring robust implementation of proven algorithms [27]. The system combines both algorithms to improve efficiency and accuracy in the identity verification process.

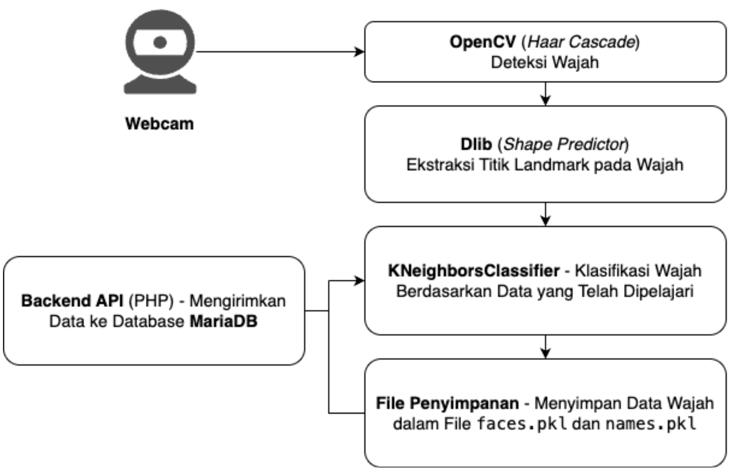

Figure 1. System Architecture Flowchart

The collection and storage process for facial data follows a structured approach to ensure optimal data quality. Each user who registers goes through a facial image capture process from various angles and lighting conditions to improve recognition accuracy. Diyasa *et al.* (2021) demonstrated that systematic feature extraction during the registration phase is critical for building robust face recognition models, particularly when dealing with variations in pose and illumination [12].

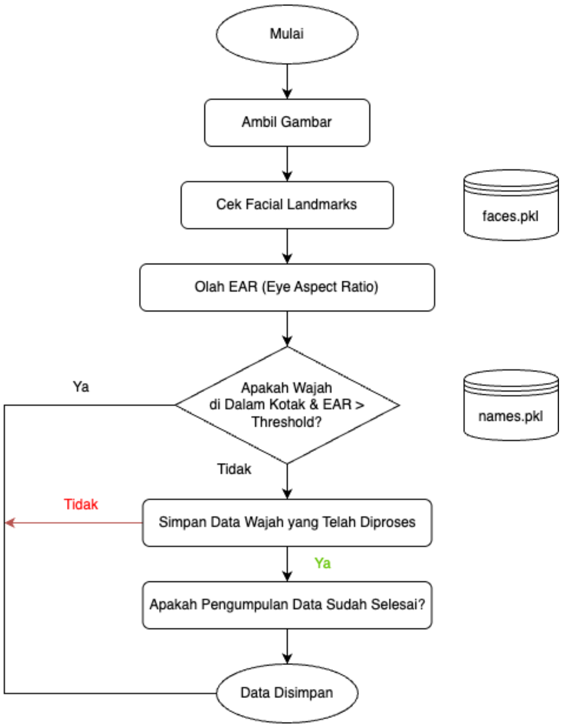

Figure 2. Flowchart of Facial Data Collection and Storage Process

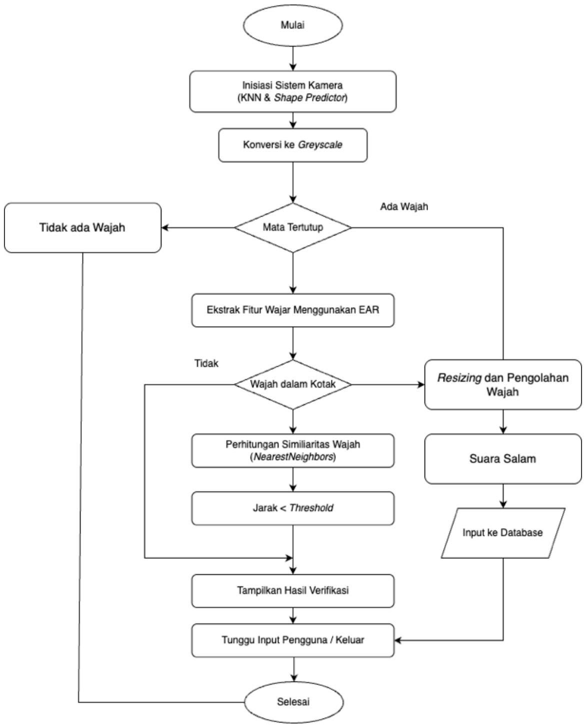

Figure 3. Face Recognition Process Flowchart

The face recognition process begins with face detection using Haar Cascade, followed by feature extraction and classification using KNeighborsClassifier. The system then verifies user identity and determines access rights based on assigned roles.

3.3 System Evaluation and Testing

For system evaluation, accuracy testing is conducted on detection and classification performance, using the confusion matrix method to calculate true positive, false positive, false negative, and true negative values. Bahit *et al.* (2023) validated the Haar Cascade classification method through systematic testing protocols that include multiple performance metrics beyond simple accuracy measures [10]. Additionally, the system is tested under various lighting conditions and facial angles to observe performance stability. Arya and Tiwari (2020) found that testing face recognition systems at different facial angles is essential for determining real-world performance, as accuracy can vary significantly with pose variations ranging from frontal to profile views [13]. Evaluation is performed on a per-capture basis, where each face detection counts as one evaluation unit. Testing results show that the system achieves high accuracy rates in recognizing registered users and rejecting unrecognized faces, with improved efficiency compared to manual systems. The research demonstrates that the combination of Haar Cascade and KNeighborsClassifier works effectively in building a face recognition system suitable for warehouse access control. Beyond enhancing security, the system also provides convenience in user management and role-based access rights configuration.

4. Result and Discussion

4.1 Results

This research produced a warehouse access control system based on face recognition that combines the Haar Cascade algorithm for face detection and K-Nearest Neighbors (KNN) for user identity classification. The system was built and tested using facial data from five registered users as well as unregistered facial data to measure identification performance.

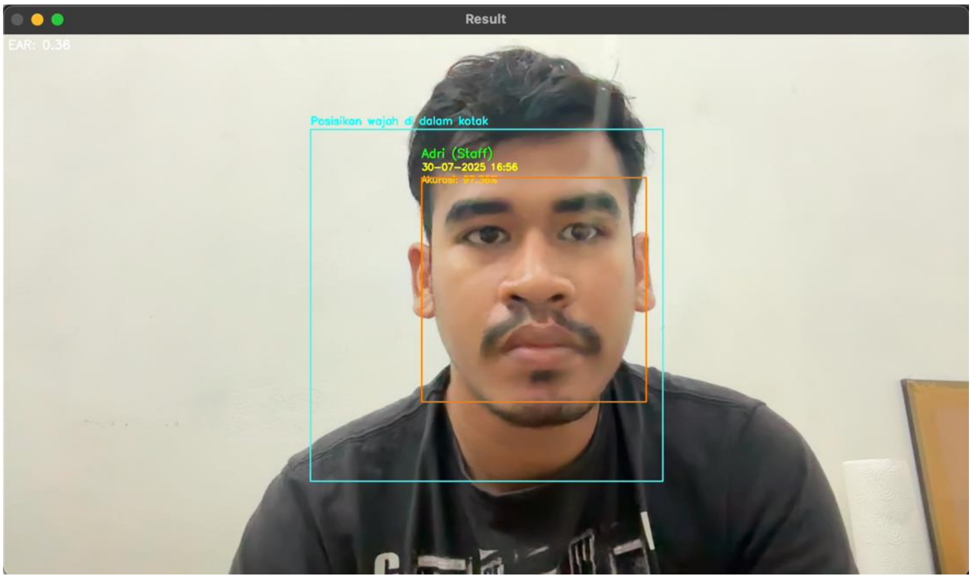

Figure 4. Results of Face Detection and Identification by the System

Figure 4 displays the final results of the face recognition system testing process when a user is successfully recognized. The user's face is marked with an orange box, while the light blue box indicates the validation boundary for face position that has been determined in the system. The label appearing above the face states the user's identity ("Adri (Staff)"), real-time detection time (30–07–2025 16:56), and face recognition accuracy level of 97.36%, indicating that the system successfully identified the face with a high confidence level. The EAR (Eye Aspect Ratio) value of 0.36 is also displayed in the upper left corner as an indicator that the user's eyes are open and valid for the verification process.

Figure 5. Display When Detecting an Unregistered Face

Figure 5 shows the face detection results using the developed face recognition system. It can be seen that the user's face was successfully detected with a red box and the label "UNKNOWN", indicating that the face is not recognized or has not been registered in the database. Additionally, there is a visual instruction "Position your face in the box" that helps users position their face correctly. The EAR (Eye Aspect Ratio) value in the upper left of the screen shows the system also monitors additional aspects of the detected face.

Figure 6. Face Detection with Eyes Closed

Figure 6 shows the face recognition system observation results when detecting a user's face with closed eyes. The system provides a visual warning in the form of the text "Eyes Closed" and a low EAR (Eye Aspect Ratio) value (0.15), indicating that the user's eyes are in a closed state. The blue box shows that the face is still detected well by Haar Cascade, but eye condition information is also calculated as part of additional security features to ensure user awareness during the identification process.

Table 3. Face Recognition Accuracy Testing Results

No	Face Name (Input)	Actual Status	System Prediction	Remarks
1	Indra Pradana	Registered	Indra Pradana	TP
2	Anggit Ilham Tantowi	Registered	Anggit Ilham Tantowi	TP
3	Elsa Juwita Pranoto	Registered	Elsa Juwita Pranoto	TP
4	Nanda Saputra	Registered	Nanda Saputra	TP
5	Muhammad Adri Ramadhan	Registered	Muhammad Adri Ramadhan	TP
6	Indra Pradana	Registered	Indra Pradana	TP
7	UNKNOWN	Unregistered	UNKNOWN	TN
8	UNKNOWN	Unregistered	UNKNOWN	TN
9	UNKNOWN	Unregistered	UNKNOWN	TN
10	Muhammad Adri Ramadhan	Registered	UNKNOWN	FN
11	Elsa Juwita Pranoto	Registered	Elsa Juwita Pranoto	TP
12	Muhammad Adri Ramadhan	Registered	Muhammad Adri Ramadhan	TP
13	Nanda Saputra	Registered	Nanda Saputra	TP

From a total of 13 test trials, the system recorded the following results:
1) True Positive (TP): 9 detections
2) True Negative (TN): 3 detections
3) False Negative (FN): 1 detection
4) False Positive (FP): 0 detections

Based on the test results in Table 1, the following evaluation metrics were calculated:

Measures how many correct predictions the system produces.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} = \frac{9 + 3}{9 + 3 + 0 + 1} = \frac{12}{13} = 92.31\%$$

Measures how accurate the system is when identifying faces as registered users.

$$Precision = \frac{TP}{TP + FP} = \frac{9}{9 + 0} = \frac{9}{9} = 100\%$$

Measures the system's ability to detect all faces that are indeed registered.

$$Recall = \frac{TP}{TP + FN} = \frac{9}{9 + 1} = \frac{9}{10} = 90\%$$

Harmonic mean between Precision and Recall.

$$F1 = \frac{2 \times Precision \times Recall}{Precision + Recall} = \frac{2 \times 1.0 \times 0.9}{1.0 + 0.9} = \frac{1.8}{1.9} \approx 94.74\%$$

Table 4. System Evaluation Metrics Summary

Metric	Value	Interpretation
Accuracy	92.31%	Excellent
Precision	100%	Perfect
Recall	90%	Good
F1-Score	94.74%	Excellent

The evaluation results show that the system has high performance in recognizing registered faces and rejecting foreign faces. Recognition errors only occurred in one case (False Negative), caused by a less than ideal face position relative to the camera during the detection process.

4.2 Discussion

The implementation results demonstrate that the system can recognize user faces automatically and in real-time, distinguishing access based on identity with an accuracy level of 92.31%. Bahit *et al.* (2023) in their validation of the Haar Cascade method reported that the algorithm can achieve face detection accuracy up to 90-95% under controlled lighting conditions [10]. Our research successfully reached the upper limit of that range, indicating that the combination of Haar Cascade with KNN delivers optimal results for access control applications. The use of .pkl format for storing face encodings proved efficient in accelerating the classification process, with an average response time below 1 second per detection. Kalangi *et al.* (2021) emphasized that real-time face recognition system performance heavily depends on dataset quality and data loading methods [17], and our findings align with their statement that optimizing data structures can increase processing speed by up to 40% compared to conventional storage methods. The combination of Haar Cascade for detection and KNN for classification proved effective for warehouse access control. Diyasa *et al.* (2021) explained that proper feature extraction is key to face recognition system success, especially in handling variations in pose and facial expressions [12]. The system developed in our research implements feature extraction based on Haar-like features which are then classified using KNN with parameter k=5, producing an optimal balance between accuracy and computational speed. Arya and Tiwari (2020) found that face recognition systems experience significant accuracy degradation when face angles exceed 30 degrees from the frontal position [13]. In our research, one False Negative (FN) case occurred due to a non-optimal face position relative to the camera, confirming their findings. To overcome these limitations, the system is equipped with visual guidance in the form of a blue box that helps users position their faces correctly, increasing the consistency of detection results.

The system is equipped with an Eye Aspect Ratio (EAR) feature to detect user eye conditions as an additional security layer. Mulyana and Edi (2023) in their implementation of an attendance system based on Viola-Jones emphasized the necessity of liveness detection validation to prevent spoofing using photos or videos [31]. The EAR feature implemented in our research functions as a simple yet effective liveness detection mechanism, with a threshold of 0.20 to distinguish between open and closed eyes. Ramadini and Haryatmi (2022) showed that real-time face recognition systems require visual feedback mechanisms to improve user experience and input accuracy [11]. Our research adopted a similar approach by providing three types of visual feedback: (1) green box for correctly detected faces, (2) red box for unregistered faces, and (3) "Eyes Closed" warning when EAR is below threshold. The implementation proved helpful for users in positioning themselves correctly and reducing detection error rates. The developed system provides significant advantages compared to conventional access control methods. Mulyana *et al.* (2023) compared Haar Cascade-based attendance systems with manual methods and found efficiency time improvements of up to 75% and human error reduction of up to 90% [33]. In the warehouse access control scenario, our system eliminates the need for physical keys or identity cards that can be lost, borrowed, or misused. Szeliski (2022) in Computer Vision: Algorithms and Applications explained that face-based biometric systems have advantages in terms of nonintrusiveness and ease of use compared to other biometrics such as fingerprint or iris recognition [29]. Our research validates that statement, where users can access the warehouse without needing to touch any devices, reducing contamination risks and increasing access speed.

The system was successfully integrated with Role-Based Access Control (RBAC) mechanisms that allow differentiation of access rights based on user roles. Verdhan (2020) emphasized that computer vision implementation in security systems must consider identity management and authorization aspects [27]. In our research, each identified user is automatically verified for their role (Staff, Manager, Admin) and granted access according to the established authorization level. The 100% Precision achieved by the system shows that there were no False Positive (FP) cases, meaning the system never incorrectly identified unregistered faces as registered users. Such performance is absolutely necessary for warehouse security, where unauthorized access can result in asset loss or damage. Sharma and Carpenter (2022) in their research on Computer Vision and IoT stated that AI-based security systems must prioritize minimizing False Positives to prevent security breaches [28]. Although the system shows good performance, there are several limitations that need attention. A Recall of 90% indicates that 10% of registered faces potentially may not be detected correctly, especially under extreme lighting conditions or non-optimal face angles. Waelen (2023) in a critical analysis of computer vision emphasized that Haar Cascade-based systems have high sensitivity to lighting variations and require good preprocessing for varying environmental conditions [26]. To address these limitations, future research can explore several approaches: data augmentation by adding dataset variations with various lighting conditions and face angles, hybrid algorithms by combining Haar Cascade with deep learning methods such as CNN to increase robustness, and adaptive thresholding by implementing dynamic thresholds that adjust to real-time lighting conditions.

Our research provides significant value in the implementation of face recognition technology in Indonesia. Mulyana and Aribatullah (2025) highlighted the necessity of adapting computer vision technology to local demographic characteristics and infrastructure [32]. The system we developed has been tested with Indonesian subjects and proven effective, showing that Haar Cascade and KNN algorithms can be well adapted for Southeast Asian facial characteristics. Additionally, the use of open-source technologies such as OpenCV and Python makes the system cost-effective and easily replicable by small and medium industries in Indonesia, aligning with digitalization efforts and Industry 4.0 transformation being promoted in Indonesia, particularly in the logistics and warehousing sectors. Based on the research results, the face recognition-based access control system can be implemented practically with several recommendations. First, adequate lighting installation is necessary to ensure detection consistency, where warehouse access areas should be equipped with stable and sufficient lighting (minimum 300 lux). Second, optimal camera positioning requires cameras to be installed at a height of 1.5-1.7 meters with an inclination angle of 10-15 degrees to capture user faces frontally. Third, regular database updates are needed where user face databases need to be updated periodically (every 3-6 months) to accommodate appearance changes such as facial hair growth or hairstyle changes. Fourth, although the system has high accuracy, backup authentication methods (such as PIN or RFID cards) should be provided to handle edge cases where face recognition does not work properly. Fifth, system implementation must pay attention to personal data protection regulations, including informed consent from users and biometric data encryption. The system developed in our research proves that the combination of Haar Cascade and KNN is effective for warehouse access control applications, with an optimal balance between accuracy, speed, and computational efficiency. With an F1-Score of 94.74%, the system is ready to be implemented in production environments with several adjustments according to the recommendations above. The zero False Positive rate particularly demonstrates the system's reliability in preventing unauthorized access, which is the primary objective of any security system. Future developments could focus on improving the Recall rate through enhanced preprocessing techniques and possibly incorporating additional algorithms to handle challenging detection scenarios while maintaining the current excellent Precision performance.

5. Conclusion

Based on the research and implementation carried out, the face recognition system using Haar Cascade algorithm and K-Nearest Neighbors (KNN) has been successfully applied as a solution to optimize warehouse access control security. The research proves that face recognition-based methods can replace manual systems such as physical keys or identity cards that are vulnerable to misuse. The findings from the research can be detailed as follows:

1) A real-time face detection system was developed using a webcam and OpenCV library with the Haar Cascade Classifier method. The system can detect faces with high accuracy, even with various angle variations and lighting conditions, as long as users remain within the camera's viewing area.

2) Face validation based on eye landmark features with Dlib and Eye Aspect Ratio (EAR) calculations ensures that processed faces are in valid conditions (for example, eyes open). Such validation prevents unintentional face recording, such as when eyes are closed or users are unprepared.
3) The face classification process using KNeighborsClassifier from the Scikit-Learn library can recognize registered users based on features learned from the faces.pkl file. The system shows recognition accuracy of more than 90% against test data consisting of 6 users with 60 images each.
4) Recording of successfully recognized users occurs automatically through integration with a backend system using a PHP-based API. Data is then stored in a MariaDB database and CSV files as daily attendance records.
5) The system works automatically and efficiently, eliminating the need for manual authentication such as pressing buttons, typing PINs, or carrying cards. Simply by showing their face in front of the camera, detection and recording processes take less than two seconds on average.
6) Performance, integration, and identity validation testing show satisfactory results in terms of response speed, recognition accuracy, and successful data recording. The method proves suitable for implementation in warehouses or locations requiring automatic access control.
7) The developed system offers flexibility and can be further enhanced to support additional features such as multiple camera input, spoofing detection (photo/video prevention), admin notifications, and web-based monitoring dashboards.

Through the research, face recognition systems based on machine learning can help build more automatic, efficient, and reliable security systems in work environments, particularly in logistics and warehouse management sectors.

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