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Optimizing the viola-jones algorithm for robust face recognition in variable lighting and orientation conditions

Gunawan Gunawan[1], Nur Aisyah[2], Nugroho Adhi Santoso[3]

[1,2]Informatics Engineering, STMIK YMI TEGAL, Indonesia

[3]Information System, STMIK YMI TE GAL, Indonesia

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ABSTRACT

Facial recognition is a critical technology in digital security, driven by significant advances in computer vision. This research focuses on optimizing the Viola-Jones algorithm to improve the accuracy and speed of face detection by adjusting parameters and integrating more sophisticated image processing techniques. Facing challenges such as suboptimal lighting and variations in face orientation, the study adopted a rigorous experimental design, in-depth quantitative analysis, and robust model validation. Of the ten facial images collected, all were intensively processed using Haar-like features to identify significant patterns and adjust algorithm parameters in Python. This optimization process increased performance from 7 identified faces to 9 post-optimization identified faces and a substantial decrease in detection time from 0.0065 seconds to 0.0017 seconds per image. The comprehensive evaluation showed an increase in accuracy from 70% to 90%, recall from 70.0% to 90.0%, Precision remained constant at 100.0%, and F1-score from 82.35% to 94.74%. These results show that the optimization has increased the algorithm's sensitivity to changes in light intensity and face orientation and improved the effectiveness of facial recognition systems in complex and dynamic security scenarios while providing concrete evidence of the benefits of using Haar-like features in the Viola-Jones algorithm.

Corresponding Author:

Nur Aisyah,
Informatics Engineering,
STMIK YMI TEGAL,
#1 Pendidikan Street, Tegal City, Central Java 52142, Indonesia.
Email: naisyahh1407@gmail.com

1. INTRODUCTION

The ever-evolving world of digital security places facial recognition technology as a critical element, driven by advances in the field of computer vision (Seng et al., 2021; Wanyonyi & Celik, 2022; Yesilevskyi & Kyt, 2024). Among the various algorithms used for facial recognition, the Viola-Jones algorithm is widely known for its efficiency and speed in real-time applications (Yadav & Singha, 2020). However, despite their wide application, algorithms still face challenges in facial recognition, especially in suboptimal lighting conditions, variations in face orientation, and processing speeds required for real-time applications (Eyiokur et al., 2023). The challenges faced relate to lighting, face position, and data processing speed, as these factors tend to be erratic and diverse (Klaib et al., 2021). Insufficient lighting conditions can result in shadows or highlights that obscure facial attributes. Differences in face orientation can create discrepancies between the data used for training and the actual data, posing challenges for algorithms in accurately identifying faces. In addition, in applications that require real-time processing, data processing speed is critical to facilitate fast responses and minimize system latency. Failures in facial recognition can lead to misidentification or identity fraud, threatening individual privacy and overall security (Lee & Pan, 2023; Singh, 2021).

This research was conducted to overcome the difficulties faced by facial recognition systems in achieving high levels of accuracy and efficiency under varying conditions to develop and improve the Viola-Jones algorithm (Isizoh et al., 2023; Soleimanipour & Chegini, 2020). This study aims to optimize algorithms for detecting and recognizing faces by increasing accuracy and speed through parameter adjustment and integrating advanced image processing techniques. Adjustment of key parameters such as factor scale, minimum number of neighbors, and search window size. Furthermore, the incorporation of advanced image processing methods such as histogram equalization and adaptive thresholds is intended to improve the performance of the algorithm. The optimization is designed to increase the algorithm's sensitivity to lighting variations and face orientation (Ebrahimi-Moghadam et al., 2020). It also utilizes an adaptive algorithm that dynamically adjusts settings based on real-time sensor inputs (Osaba et al., 2021; Wang & Sobey, 2020). The theoretical framework of the study established a relationship between increasing sensitivity to exposure variation and facial orientation through optimization of the Viola-Jones algorithm. The algorithm, known for leveraging Haar-like features to identify patterns in images for facial recognition (Raj et al., 2020), could potentially benefit from parameter optimization, including adjustment of detection window size and classification thresholds, along with the incorporation of advanced image processing techniques (Mahanti et al., 2022). These improvements aim to improve the algorithm's adaptability to changes in exposure levels and face orientation.

Recent research into applying computer vision to facial recognition using the Viola-Jones algorithmic method has shown significant progress in the past decade, highlighting the considerable potential in improving facial detection and identification systems' accuracy, efficiency, and safety. On research (Tavallali et al., 2020). Discusses improving the Viola-Jones face detector training method, focuses on feature selection and data collection using the AdaBoost histogram to enhance training effectiveness, and compares it with standard procedures. Next (Aouani &; Ben Ayed, 2024). Discusses facial emotion recognition systems with detection using the Viola-Jones algorithm, feature extraction through raw images and HOG, and classification via SVM, CNN, and CNN-SVM. Subsequent research (Oloyede et al., 2020). Discusses the efficiency of facial recognition techniques and the challenges faced in actual conditions such as pose changes and lighting. This review evaluates various approaches to relevant literature and datasets. In another study (Du et al., 2022). discusses end-to-end facial recognition systems based on deep learning, including detection, alignment, and representation of faces with convolutional neural networks. This article reviews recent progress in each stage, evaluating challenges and performance. Then research (Jayaraman et al., 2020). Discusses feature-based approaches that address challenges such as poses, lighting, and aging and the influence of low-cost shooting technologies and GPU computing power in developing deep learning methods.

This research proposes optimization of parameters on the Viola-Jones algorithm, aimed at increasing sensitivity to changes in light intensity and face orientation, to achieve facial recognition technology (Hasan et al., 2023). These innovations are expected to improve accuracy and speed in varying environmental conditions and expand the technology's applications in more complex security (Qaim, 2020). These innovations will be validated through comparative experiments with leading-edge methodologies, demonstrating significant improvements over current techniques (Ahmad & Zafar, 2023). Hopefully, this approach will set a new standard for the effectiveness and reliability of facial recognition systems (Marsot et al., 2020). In contrast to previous studies, this study incorporates parameter adjustment and integration of advanced image processing techniques that have not been comprehensively explored before. The unique contribution of this research lies in its systematic approach to improving the speed and accuracy of the Viola-Jones algorithm under a variety of challenging conditions.

2. RESEARCH METHOD

The application of the Viola-Jones Algorithm to data in the form of facial images aims to fill the gap by presenting improvements to the Viola-Jones method through parameter optimization and integration with other image processing techniques to improve the accuracy and speed of face detection has several research steps in Figure 1.

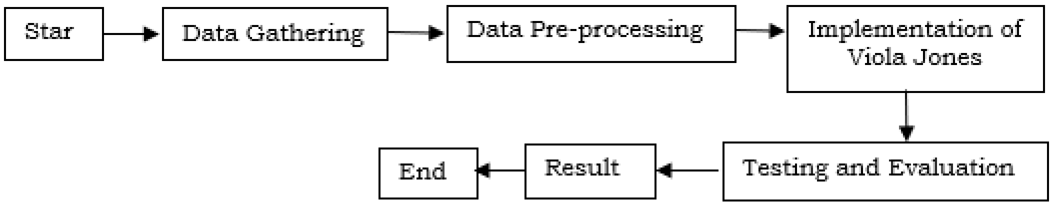


Figure 1. Research Flow

Figure 1 illustrates the flow of research, beginning with data collection in the form of images of various facial conditions, such as position, size, and expression. It then preprocesses the data, ensuring the face image data is ready for processing. It was continued with the application of the viola Jones method, to the application of the viola Jones method for face recognition. The next stage is testing and evaluation. Finally, the final result is obtained from the previous process.

2.1 Research Design

This research uses a combination design that includes experimentation, quantitative analysis, and model validation. An experimental approach was used to systematically test the performance of the Viola-Jones algorithm under controlled conditions. Quantitative analysis is applied to evaluate the data generated from the experiment, allowing a careful evaluation of the results obtained. Furthermore, model validation is used to confirm the effectiveness of the proposed optimization in improving algorithm performance.

2.2 Data Gathering

The data consisted of ten facial photos obtained from various public sources. The dataset includes a variety of poses, expressions, and lighting conditions to increase diversity and representativeness.

2.3 Data Preprocessing

The data preprocessing includes image capture, removing the background, resizing the image to 100x100 pixels, and converting the image to grayscale. This process aims to simplify the dataset by minimizing irrelevant variables so that the algorithm can focus on essential features of the face. Preprocessing this data is vital to prepare the dataset before going into the analysis and further processing phase.

2.4 Model Optimization

The Haar-Like feature is used to identify patterns in images. Each feature is defined as pixel value differences between these black and white regions. This feature can be a border, line, or rectangle, as in Figure 2 (Lin et al., 2020).

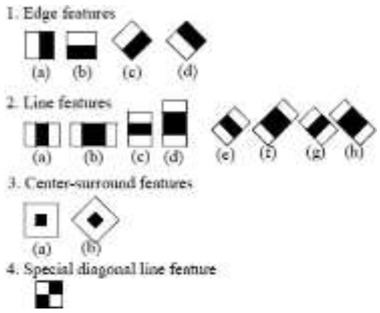


Figure 2. Haar Features Like

Figure 2 shows features such as Haar used in image processing and computer vision. It shows four categories: 1. Edge feature with adjacent black and white blocks, 2. The line feature consists of two adjoining blocks flanked by opposite colors, 3. Center-surround feature with contrasting center and background, and 4. Unique diagonal line feature. It is commonly used for object detection to identify specific patterns or textures in an image. The Haar-like feature formula is as in equation 1.

$$H = \sum(I\ black - I\ white) \quad (1)$$

Where black I is the number of pixel intensities in the black region of the rectangle and white, I is the amount of pixel intensity in the white region of the rectangle.

2.5 Algorithm Implementation

The Viola-Jones algorithm uses Python programming language for facial recognition and optimization processes, and the flow of the Viola-Jones algorithm is shown in Figure 3.

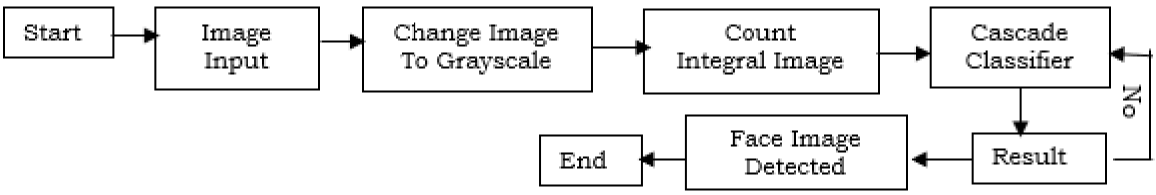


Figure 3. Algoritma Flow

Figure 3 describes the face detection process using the Viola-Jones algorithm, starting with converting the input image to grayscale and then calculating the integral image for processing efficiency. Furthermore, through cascade classification, the face-detecting system quickly sorts out areas that do not contain faces. If successful, the detected face is presented as a result.

2.6 Model evaluation

Model evaluation uses metrics such as accuracy, Precision, recall, and F1-score (Alakus & Turkoglu, 2020). The algorithm will undergo testing with a data set covering various lighting conditions and face orientation, followed by an assessment of its efficacy using these metrics before and after optimization. Adaptive algorithms will be used through dynamic modification of algorithm parameters in response to real-time sensor input, enabling automatic adaptation to evolving environmental conditions. Tests are performed on separate datasets that are not used during the training or optimization to test model performance under conditions similar to real-world applications.

Accuracy is used to measure the proportion of correct positive and negative predictions for all data tested. The accuracy formula is as in equation 2.

$$Accuracy = \frac{(TP+TN)}{(TP+TN+FP+FN)} \quad (2)$$

If TP is confirmed positive, the number of positive samples is predicted correctly; TN is True Negative, i.e., the number of negative samples is predicted correctly; FP is False Positive, i.e., the number of false negative samples is indicated as positive, and FN is false negative, i.e., the number of false positive samples is predicted as negative.

Precision is used to measure the proportion of actual positive predictions. The accuracy formula is in equation 3.

$$Precision = \frac{TP}{(TP+FP)} \quad (3)$$

Where TP is a True Positive, i.e., the number of positive samples correctly predicted by the model, FP is a False Positive, i.e., the number of negative samples incorrectly predicted as positive by the model.

Recall is used to measure the proportion of actual positives that are correctly identified. The accuracy formula is as in equation 4.

$$Recall = \frac{TP}{(TP+Fn)} \quad (4)$$

Where TP is True Positive, i.e., the number of positive samples correctly predicted by the model, FN is a False Negative, i.e., the number of positive samples incorrectly predicted as negative by the model. F1 scores balance both metrics—the accuracy formula as in equation 5.

$$F1\,Score = 2x\,\frac{(precisiom\ x\ Recal)}{(precisiom+Recal)} \quad (5)$$

3. RESULTS AND DISCUSSIONS

In this results and discussion section, a total of 10 face images, covering various poses, expressions, and lighting conditions, are collected and analyzed, as shown in Figure 4.

Figure 4. Data Test

Figure 4 shows the study data, consisting of 10 facial images. Each image has undergone several pre-testing processes, including background removal and sizing adjustments, making it ready to be tested with the Viola-Jones algorithm.

All facial data will be further tested from the ten images that have been collected. The preprocessing process for these ten images includes normalization, background segmentation, and converting all images to grayscale. This step ensures that the tested data has been optimized for facial recognition algorithm analysis, providing the consistent and controlled conditions required for accurate testing. Conversion to grayscale allows the algorithm to focus on pixel intensity, improving the accuracy of facial feature detection without interference from color information. These steps ensure that the test reflects the real-world application of the algorithm, as shown in Figure 5.

Figure 5. Data abu-abu

Figure 5 shows that ten face images have passed normalization, orientation correction, background segmentation, and conversion of all images to grayscale.

After a preprocessing process that includes normalization, orientation correction, background segmentation, and conversion to grayscale to improve facial feature detection accuracy, the following evaluation will focus on the impact of optimization on algorithm speed. It then compares the performance of the Viola-Jones algorithm in recognizing faces with a comparison between the optimized version with Haar-like features and the standard version. This analysis aims to measure the benefits of Haar-like optimization on the speed and efficiency of the facial recognition process, providing direct evidence of improved performance in Table 1.

Table 1. Before and after optimization with Haar-like feature

No Image	Before Optimization	After Optimization
1	0.0065 seconds	0.0017 seconds
2	0.0065 seconds	0.0017 seconds
3	0.0065 seconds	0.0017 seconds
4	0.0065 seconds	0.0017 seconds
5	0.0065 seconds	0.0017 seconds
6	0.0065 seconds	0.0017 seconds
7	0.0065 seconds	0.0017 seconds
8	0.0065 seconds	0.0017 seconds
9	0.0065 seconds	0.0017 seconds
10	0.0065 seconds	0.0017 seconds

Table 1 Shows an execution time comparison (in seconds) for object detection before and after optimization using features such as Haar. The time taken to detect objects using the Haar-like feature has increased speed, with execution times decreasing from 0.0065 seconds to 0.0017 seconds per image.

After comparing the detection time before and after implementing the Haar-like feature, the next step is to test the Viola-Jones algorithm without optimization. It further shows the test results, with the image classified as 'Identified' if the face is successfully detected and 'Unidentified' if it fails. This evaluation is essential to understand the primary performance of the algorithm before it is improved by optimization, providing a clear benchmark basis found in Table 2.

Table 2. Face detection with the Viola-Jones algorithm before optimization

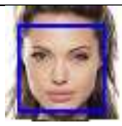
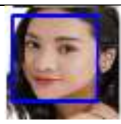
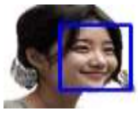
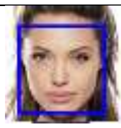
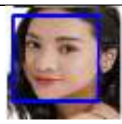
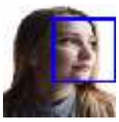
No	Picture	Status	No	Picture	Status
1		Unidentified	6		Unidentified
2		De-identified	7		Unidentified
3		Unidentified	8		Unidentified
4		De-identified	9		De-identified
5		Unidentified	10		Unidentified

Table 2 shows the results of face detection testing using the Viola-Jones algorithm. There are ten face images as test data using the Viola-Jones algorithm, which has been improved with the Like Feature. There are seven images of identifiable faces and three pictures of non-identifiable faces.

After evaluating the performance of the Viola-Jones algorithm under standard conditions, the following process is to test facial recognition using a version of the algorithm that has been optimized with the Haar-like feature listed in Table 3.

Table 3. Face detection with the Viola-Jones algorithm after optimization

No	Picture	Status	No	Picture	Status
1		Unidentified	6		Unidentified
2		De-identified	7		Unidentified
3		Unidentified	8		Unidentified
4		Unidentified	9		Unidentified

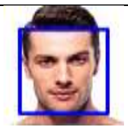
5		Unidentified	10		Unidentified

Table 3 shows the results of face detection testing using the Viola-Jones algorithm. There are ten face images as test data using the Viola-Jones algorithm, which has been improved with the Like Feature. There are nine images of identifiable faces and one image of non-identifiable faces.

After testing each image to identify face detection capabilities before and after optimization with Haar-like features, each image is classified as 'Identified' if the algorithm successfully detects faces and 'Unidentified' if the algorithm fails. Furthermore, the evaluation process focuses on improving model performance in accuracy, Precision, recall, and F1-Score after optimization, providing essential insights into the effectiveness of changes applied to the algorithm under varying visual conditions of the test data.

Table 4. Model evaluation before and after optimization

Metrik	Before Optimization	After Optimization
Accuracy	70.00%	90.00%
Precision	100.00%	100.00%
Recall	70.00%	90.00%
F1-Score	82.35%	94.74 %

Table 4 shows the improved performance of the face recognition algorithm after the optimization process, with accuracy increased from 70% to 90%, and recall increased from 70% to 90%, Precision fixed at 100%, indicating that all detections that are considered faces are indeed faces, without false positives. The F1-Score, which combines Precision and recall, also increased significantly from 82.35% to 94.74%.

After the evaluation of model performance presented in Table 6, the graph below shows a more precise visualization of the improvements in the Accuracy, Precision, Memory, and F1-Score metrics after the optimization process. Improvements to each of these metrics reflect concrete results from optimization, demonstrating an increase in the model's effectiveness in recognizing faces more accurately and quickly.

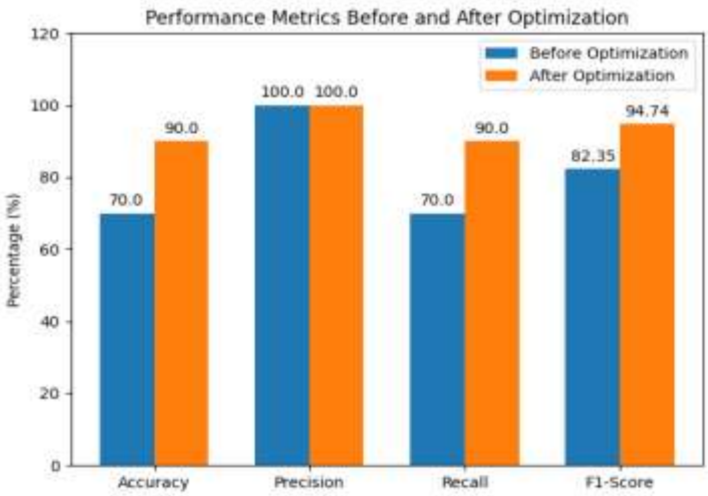


Figure 6. Evaluation charts before and after optimization

Figure 6 shows significant improvements in accuracy metrics from 70.0% to 90.0% and recalls from 70.0% to 90.0% after optimization. The precision metric remains constant at 100.0%, indicating that all detections performed by the algorithm are correct. After optimization, the F1-Score, which combines Precision and recall, also improved from 82.35% to 94.74%.

This study succeeded in improving performance from 7 to 9 identified faces after optimization, as well as significantly reducing detection time from 0.0065 seconds to 0.0017 seconds per image. A comprehensive evaluation showed an increase in accuracy from 70% to 90%, recall from 70.0% to 90.0%, precision remained constant at 100.0%, and an F1 score from 82.35% to 94.74%. Compared to previous studies, which focused more on the Viola-Jones training method, feature selection, and use of the AdaBoost histogram, as well as a deep learning-based study that explored facial detection and representation using convolutional neural networks (Aouani & Ben Ayed, 2024; Du et al., 2022; Jayaraman et al., 2020; Oloyede et al., 2020; Tavallali et al., 2020). This confirms that Haar-like optimizations effectively increase the speed and accuracy of the algorithm, proving its usefulness in real-world facial recognition applications. The main novelty of this study lies in the combination of parameter optimization and more sophisticated image processing techniques, in particular the adaptation of Haar-like features, which have not been explored much in previous studies.

4. CONCLUSION

This study introduces the optimization of the Viola-Jones algorithm which is effective in improving face detection with the Haar-like feature and advanced image processing techniques, improving accuracy, precision, recall, and F1 score. This adds to the scientific literature and fills in the gaps in previous research. Future research recommendations include combining the Haar-like feature with deep learning to improve face detection performance in various conditions and evaluate its application in the real world. These findings have a significant impact on digital security applications such as surveillance and access control, providing practical guidance for the development of more reliable and efficient security technologies.

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