Implementation of face recognition using Python

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ABSTRACT

Artificial intelligence (AI)-based technology systems are developing rapidly. Along with technological development the number of criminal cases caused by facial forgery is also growing. Cases of theft and housebreaking with fake photos are a common problem in Semarang. In 2022–2023 the number of cases of theft and housebreaking reached 372,965 with a crime risk level of 137/100,000 people. To overcome this problem the facial recognition system used in the door security system uses digital image processing. This method works by imitating how nerve cells communicate with interconnected neurons, or more precisely, how artificial neural networks function in humans. As training data, image capture and facial recognition are carried out using a webcam and the Python programming language with the TensorFlow library. The image processing algorithm uses 400 facial images with an accuracy rate of 95%. However further development is needed to improve the efficiency and accuracy of the system to produce better results.

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1. INTRODUCTION

Home security is important to avoid crime problems such as house robbery. According to the central statistics agency of Semarang city, Indonesia, crime cases in 2022-2023 reached 372,965 with a risk level of 137/100,000 residents [1]. The increasing number of theft and robbery cases in housing is a consideration for tightening the current security system. Although most housing is provided with closed-circuit television (CCTV), facial recognition technology is needed to ensure that only people with access are allowed to enter the house [2]. The use of password-type security such as using letters and numbers often results in errors and is vulnerable to hacking because based on CNBC Indonesia data in 2022, the password hacking rate increased by 921 attacks per second, plus data according to the Microsoft Digital Defense Report shows an increase of up to 74% in one year. Therefore, the use of facial passwords is the best solution to prevent house theft [3]. Deep learning is developed using a machine learning approach that has a working principle of a facial detection camera system with an accuracy equivalent to the ability of the human brain. Even the accuracy produced reaches 98.8% on a 64×64×3 face, but is also supported by the quality of the camera used to process facial recognition. Its implementation uses the single-shot detector (SSD) method, which is one of the digital image processing methods [4], [5].

The use of digital image processing methods is a method that has the highest accuracy both statistically and in real time [6]. The recorded accuracy level is 100% when the viewing angle is facing forward, then when not facing forward, the highest accuracy level is 80%, but with a distance range of 60-250 cm from the face detection camera [7], [8]. Real-time facial recognition research has been conducted and has an accuracy result of 87% using the convolutional neural network (CNN) method with 372 data points, including 186 male image data and 186 female image data [9], [10]. Another research used 1,100 images, with 550 being male image data and 550 female image data. Producing an accuracy value of 90% for age and 96% for gender using the CNN method [11]. Research entitled "optimizing gender classification accuracy in facial images using data augmentation and inception V-3" using the inception V-3 and convolutional methods with 290 data consisting of 145 men and 145 women produced the best accuracy value of 99.31% [12], [13].

Although facial recognition technology has been advanced, most of the systems created are limited to theoretical validation or rely on high-performance GPUs. The focus of this research is on the efficiency of limited hardware and resources by developing a lightweight and accessible facial recognition system. This system is specifically designed for home security. The distinguishing value of this research is the implementation of digital image processing for a security system with a high level of accuracy. Digital image processing can identify and recognize recorded faces precisely. By using this system, access control in a room in the house can avoid the risk of hacking and access by faces that are not recognized by the system, so that it can be secured [14]. The use of the digital image processing method has been proven to provide results with a high level of accuracy, according to research that has been conducted on digital image processing, which can recognize facial images better than other methods that have been tested [15]. Therefore, the use of this method will be very suitable for implementation as a form of room security technology that requires variations in facial expressions to uncertainty in changes in appearance [16].

This research was conducted to determine how the application of the digital image processing method as facial recognition in home security systems and whether digital image processing can produce a good level of accuracy for human facial recognition. It is expected that this technology can distinguish between known and unknown faces so that only confirmed faces can be authorized to enter the area. The system does not require special devices so that it is affordable and increases accessibility in its application, especially in residential areas that require more security. The purpose of this research is to implement a facial recognition system using digital image processing and deep learning tools based on Python and OpenCV then evaluate the accuracy and robustness of the system in real-world constraints including lighting variations and various facial poses. Another objective is to demonstrate the feasibility of implementing the system on low-cost hardware for residential security use and system performance will be measured through quantitative metrics including accuracy, precision, recall, F1 score, and confusion matrix analysis.

2. METHOD

The face recognition system using digital image processing requires analysis to cover various variations of human faces from various practical conditions. These conditions may occur in the use of the system and must be addressed properly. Some of the analyses that need to be carried out by digital image processing include data analysis, process analysis, system design, and system implementation.

2.1. Data analysis

The data source consists of a dataset of human facial images trained through image samples with various poses, expressions, lighting, and different backgrounds. The purpose of this variation is for digital image processing to be able to understand and recognize registered faces from various conditions. The total amount of trained image data is adjusted to the number of subjects involved and to the desired variation. Furthermore, test image data and performance tests of trained data are carried out. This test is carried out to evaluate the reliability of the system in recognizing faces that have been registered by digital image processing [17].

2.2. Process analysis

This process performs an in-depth analysis related to the face recognition process in digital image processing by considering the application built and the specifications of the registered dataset. The first stage is image acquisition, where data that has been entered into the system can detect people's faces using a real-time camera. Each face detected by the system is identified and named. The success of the system can be indicated by the appearance of a name on the face that has been registered, and the camera can consistently detect individual faces quickly and accurately from various conditions [18]. The next stage is the face detection stage, face detection using digital image processing assisted by the OpenCV library [19], [20]. This process is carried out to find the presence of a face in the camera frame. This face detection uses the concept of Haar features, integral image, and cascade classifier so that the face detection process runs efficiently [21].

The third stage is pre-processing, which is the process of improving image quality before the next process is continued. This process requires cropping on the target face only and removing irrelevant areas, then the image resizing process so that when the image is converted to grayscale mode it is easy to extract and reduce noise and contrast adjustments and when changing the color to grayscale are done to focus information for more efficient and accurate face recognition. The next is the feature extraction stage, taking important features based on the registered data to distinguish between faces. The extracted features include visual patterns that represent unique features of the registered face [22]. The final stage is face matching by measuring the level of similarity between the training image and the test image with a digital image processing method. This process compares the characteristics learned by the system, so that it can accurately detect the visuals seen.

2.3. System design

The design of a facial recognition system requires several considerations, such as system architecture design, a facial recognition model that meets specifications, a camera for facial image acquisition, software for implementing facial recognition algorithms, and its interface. The system design has a facial detection process starting with image input, followed by a pre-processing process. After that, the feature extraction process, classification process, and image output are carried out. The application of face recognition for home security systems begins by capturing facial images with the camera and automatically converting them from RGB images to grayscale images. The use of the Haar cascade classifier method to detect faces captured by the camera is marked by a blue circle on the face that has been detected [23].

The contents of the dataset are various facial images that represent subjects from various conditions when taking pictures, so that the system can recognize faces as a whole, up to various situations that occur. The design of this system requires data pre-processing such as cropping, resizing, and converting to grayscale. This process needs to be done to improve the accuracy of facial recognition [24]. The flow of dataset creation is as follows in Figure 1.

The face detected by the camera will be known by its histogram. The system will compare the histogram value of the face detected by the camera with that in the database. The face will be recognized if its histogram value is most similar to the data. By applying the local binary pattern histogram algorithm, the camera can automatically compare histograms on the face [25]. The face recognition flow is shown in Figure 2. The design of digital image processing applications for facial recognition systems has important steps for its management, such as dataset separation, processing learning, prediction, evaluation, and digital image processing architecture design [26], [27].

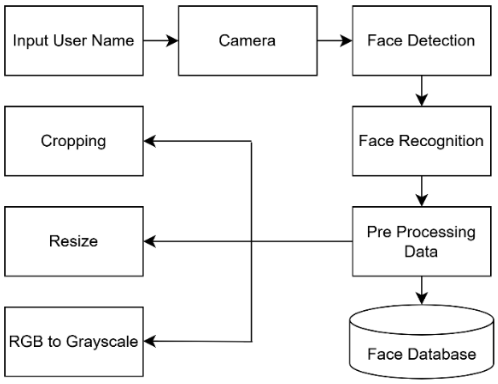

Figure 1. Dataset creation flow

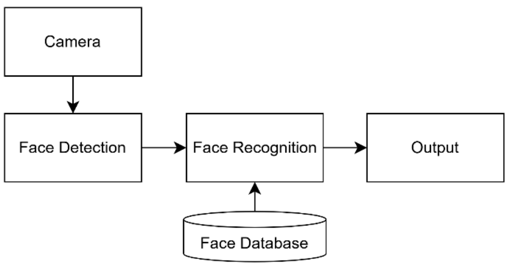

Figure 2. Face recognition flow

2.4. System implementation

Dataset separation is the beginning of the implementation of a system consisting of several facial images that are separated into two parts, namely training data and test data. Training data will be used to train the digital image model, while test data will be used to test the performance of the trained model. Then the digital image processing process is carried out using training data to train digital images. The process involves forward propagation and backward propagation to optimize model parameters on facial patterns.

Digital images are trained to make predictions on newly seen facial images. The process is carried out by classifying previously unseen facial images that have been learned from digital images. The results will later be used to identify related individuals. Evaluation is the final stage to measure the performance of the digital image model. Some of the evaluation measures are accuracy, precision, recall, and F1 score. This evaluation is carried out to assess the level of sensitivity of digital images in recognizing faces accurately or not. Haar Cascade excels in speed and simplicity but multi-task cascaded convolutional network (MTCNN) or YOLO are superior for complex and high-precision applications especially in poor lighting conditions, rotations, or varying expressions.

3. RESULTS AND DISCUSSION

The hardware implementation environment used has the following specifications, including processor: Intel Celeron N4020 (2C/2T, 1.1/2.8GHz, 4MB), screen: 14″ HD (1366×768) TN 220nits anti-glare, memory: 4GB DDR4-2400MHz, 256GB SSD M.2 2242 PCIe 3.0×2 NVMe storage, integrated Intel UHD Graphics, and 2 cells 35WH35 battery.

Next is the software implementation environment used, such as the programming language used is Python 3.6, which has flexibility and many supporting libraries in image processing. Python has an easy-to-understand syntax and ease in utilizing various latest tools and techniques in application development. The libraries and frameworks used in this study are TensorFlow: 2.16; Keras: 3.0.5; Scikit-Learn: 1.4.1; Pandas: 2.2.1; OpenCV: 4.9.0.80; Matplotlib: 3.8.3; and NumPy: 1.26.4. development tools using Jupyter Notebook, Spyder, and Tkinter. The right combination of programming languages and libraries will make it easy to develop applications with satisfactory and efficient results.

Implementation of facial recognition is done by separating the dataset according to the name that has been registered in the system. Grouping according to this data is done based on the face of each individual, who will create a folder containing sample images of their face. The create_directory function will create a folder that will divide the type of face. Furthermore, the system will perform an OpenCV face detector using a webcam. The detected image will be stored in the directory according to the name registered to distinguish the sample. After the detected face enters the directory, the next step is processing the dataset for faces that have been categorized by name. The images that have been entered are converted to grayscale to reduce the data dimension, but still get the required data, namely the visual characteristics of the facial image. Before being converted to grayscale, the image will be cropped so that only the face part is obtained as the required data, then the image that has gone through the cropping process will be resized to 100×100 pixels so that the size is uniform and by the digital image model. Only after that are the images converted to grayscale to facilitate analysis and efficiency of the digital image model, so that the dataset is ready to be used in facial recognition, as in Figure 3.

Next, the face recognition system using digital images will recognize known faces according to those registered in the OpenCV library. The recognition system can directly use the camera in real-time. The results of this recognition will show the name of the registered face user continuously, as in Figure 4.

The creation of the basic concept of digital image architecture, covering the main layers in the formation of digital image structures such as convolutional layers, pooling layers, and fully connected layers, is carried out at this stage. Each layer will extract from each facial recognition feature and combine them into one unit for accurate prediction results. The first layer is a convolution (Conv2D) with 32 filters measuring 3×3 with the rectified linear unit (ReLU) activation function. Image input uses a color image with dimensions of 100×100 pixels. Followed by a MaxPooling layer (MaxPooling2D) measuring 2×2 to reduce the image dimension. After both of these things run, the results will be done for flattening (dlatten), which changes the vector to dimensions. The vector will be forwarded to the dense layer with 128 units and uses the ReLU activation function. The dense report provides output according to the number of faces recognized using the softmax activation function to produce prediction probabilities for each class.

The description and rationale for parameter selection are from 32 filters and 3×3 kernel with small size and efficient for initial feature detection because 32 filters are sufficient for small datasets. MaxPooling 2×2 commonly used to reduce the size of the feature map while preserving important features. In addition, ReLU serves as a popular activation function because it avoids the vanishing gradient problem and softmax used for multiclass classification in the output layer.

The model training process uses the Adam optimization algorithm to produce optimal prediction probabilities. The way the Adam method works is to update the parameters of the model based on the gradient and loss function, so that periodically, the performance of the system's decision selection from its predictions becomes better [28]. The results of the analysis show that the evaluation matrix obtained is accurate to help determine how well the model matches facial images in each category. Then, the precision evaluation is carried out to understand the reliability of the model in identifying facial images from its class [29]. Recall or sensitivity level to measure the proportion of the predicted results to the actual positive data. F1-score is a metric that combines precision and recall into one number. F1-score provides an overview of the quality of the mode prediction and considers its balance. Evaluation results will provide insights related to the performance of the digital image model. The data shown are accuracy, evaluation matrix, and heatmap confusion matrix.

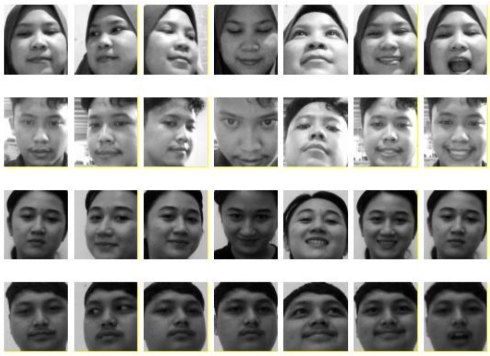

Figure 3. Image dataset

Figure 4. Facial recognition process

3.1. Training and validation accuracy graph

Accuracy and validation training process looks at how well the model learns the data and generalizes to the test data. Changes in model accuracy are made along with the addition of epochs indicated by the training accuracy on the blue line to show how well the model learns the training data will remembers the patterns in the data. The orange line which is the validation accuracy shows how well the model generalizes new data that is not in the training directory to avoid adjusting new data. The results of the validation training and validation accuracy indicated by the blue and orange lines are depicted in a chart in Figure 5. Based on the epoch versus accuracy graph, this model achieves a level of accuracy stability reaching 3 epochs with a training accuracy reaching 95% with high and stable validation accuracy.

3.2. Evaluation matrix graphic

Scope of the evaluation matrix is accuracy, precision, recall, and F1-score. This evaluation helps to find out the strengths and weaknesses of the model for clustering, as in Figure 6. Assessment of the evaluation matrix shows a range of 0 to 1. If it shows the number 1, then the performance of the model is optimal. The graph in Figure 5 shows the maximum value, which is 97.5%, with good performance in recognizing and classifying facial images with a high level in each evaluation matrix.

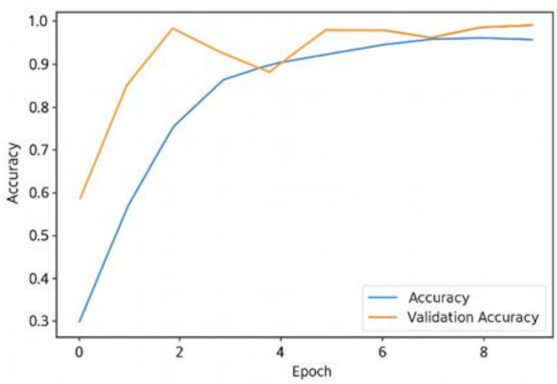

Figure 5. Validation training accuracy chart

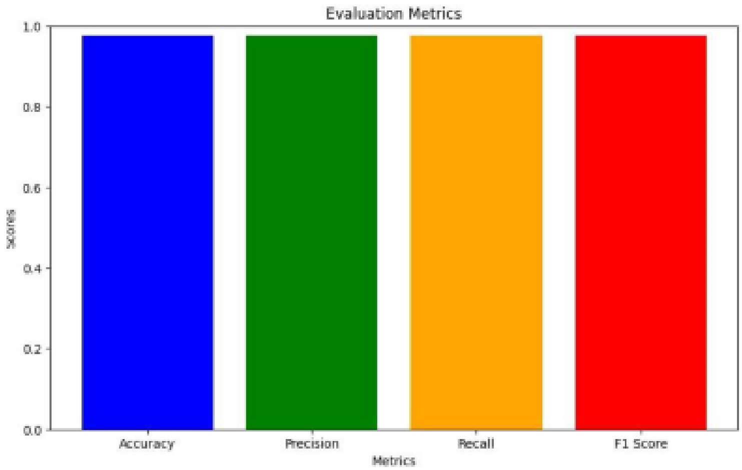

Figure 6. Evaluation matrix graphic

3.3. Heatmap confusion matrix

Evaluation table of the classification model performance in the row table is the actual label, and the column table is the predicted label. The distribution of model predictions in color shows how well the model predicts, or there are errors. There are four classes registered, namely Fadia, Vicky, Arifin, and Aisyah. The matrix shows the value of the number of predictions formed by the model in each class and compared to the actual class. The actual label class has 4 names registered in the model. Diagonally from left to right, the number of model prediction values in predicting the correct label. In the Fadia class, it shows 6 correct predictions, the Vicky class has 15 correct predictions, the Arifin class has 9 correct predictions, and the Aisyah class has 10 correct predictions. In other cells that show incorrect predictions, there is only 1 prediction error. The color and scale in the table show that the dark color is the high frequency, and the scale on the right shows the range of values associated with the matrix color. It can be concluded that this model can predict accurately and effectively without any lack of variation in the test data as shown in Figure 7.

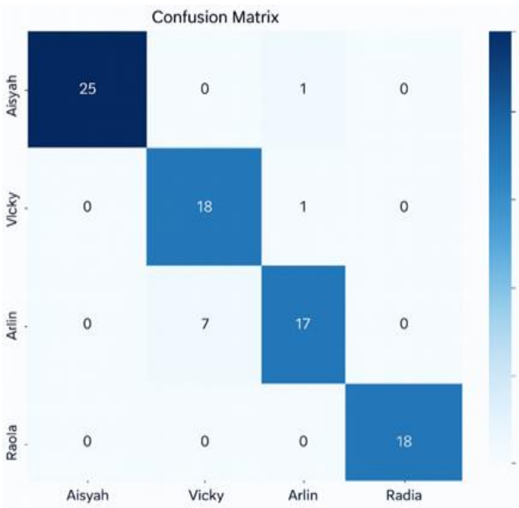

Figure 7. Heatmap confusion matrix

The testing process uses a graphical user interface (GUI) display program with an HTML-based command script and is compared with the Python language to run the camera and digital image model algorithm. The initial step is to enter the username to retrieve facial image data 100 times and then save it in a folder according to the username. The next step is to test the registered face detection system, each of which is tested 5 times. Based on the testing of the four user faces, each of which was tested five times and accumulated over 20 trials, only one detection error was found, namely in user Vicky in her third test as an unknown face, as in Table 1. Cause of the failure of identification of the identification of the Vicky user is due to lighting that is too bright or too dark, so that facial detection to identify moving faces has difficulty. The level of accuracy of the results of this test is calculated using a percentage that produces 95% based on 19 out of 20 successful tests.

Table 1. Table results

Num	Username	Testing	Identification results	Status
1	Fadia	5 times	Fadia	5 Successfully
2	Vicky	5 times	4 Vicky 1 Unknown	4 Successfully 1 Failed
3	Arifin	5 times	Arifin	5 Successfully
4	Aisyah	5 times	Aisyah	5 Successfully

4. CONCLUSION

The conclusion that can be drawn is that the accuracy of the digital image model reaches around 3 epochs. The training accuracy reaches 95% with high and stable validation accuracy. So that the model can learn patterns in the data well and can generalize to the test data. The maximum value obtained is 97.5% therefore, the model has succeeded in doing its job in recognizing and classifying faces well by showing high levels of accuracy, precision, recall, and F1 scores. System analysis related to face recognition with the algorithm method conducted 20 trials with 4 face names, as many as 400 images of different faces, getting a program accuracy level of 95%, and from the overall recognition, there was only 1 error in recognition. Performance needed for further development is better and more complex, which requires the need to use a higher quality GPU and a higher RAM size so that the dataset can be expanded and the process of understanding variations becomes better. The facial recognition system can also be tested again with certain cases such as facial rotation, facial expression variations, different lighting, and age. Edge deployment optimizes the model to run efficiently on Raspberry Pi, Jetson Nano, and others. Emotion detection can also be added by adding an emotion classification module to detect suspicious expressions. Multi-face tracking with ID for crowd recognition scenarios along with spoofing defense for liveness verification, blink detection, or live skin texture can enhance this system.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

No data are available for sharing as this research did not use an external dataset.

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