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House Door Security Design System Based on Face Recognition on ESP32-CAM

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ABSTRACT

Currently, the incidence of theft crimes by breaking into house doors is increasing. The importance of a security system is to prevent unknown parties from stealing or violating privacy without the owner's consent. Biometric technology can create a strong security system, by using the biological characteristics that every human has, such as fingerprints, facial detection, eye retina and voice. One of the biometrics that is considered strong when building a security system is facial recognition. This research uses the Haar Cascade Classifier algorithm supported by OpenCV to increase the accuracy of facial identification based on facial structure and eye feature extraction. The training and testing process is carried out directly (real time) using the OV2640 camera and dataset. The designed prototype consists of an ESP32 CAM microcontroller, relay, and door lock solenoid which is integrated with telegram as notification. Based on the test results, it shows that the accuracy of matching facial images using the Haar Cascade Classifier algorithm which matches the database is 80%. Apart from that, the results of testing the distance of the face to the camera, variations in light, position and facial expressions that can be recognized with the ESP32 CAM camera greatly influence the face detection process. In this case, the effective distance is 25-55 cm in light conditions with a light intensity of 83-450 lux, and the face is facing forward. Apart from that, the system is also able to differentiate between human face objects and non-human face objects. The tool's performance from detection to sending unrecognized image data to Telegram took an average of 6.4 ms. From the test results, it is also known that the perfection of facial appearance that can be recognized with the ESP32 CAM camera has a great influence on the face detection process

Keywords: Home Security, ESP32 CAM, Selenoid Door Lock, Face Recognition, Telegram.

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1. INTRODUCTION

Currently, the crime rate continues to increase, recording 372,962 crime incidents during 2022 (Statistics, 2023). One of them is theft by breaking into the door of the house by breaking the lock and door hinges, so that the house becomes more of a threat because of the many activities of the residents which often require them to be active outside the house (Naser Abbas Hussein, 2017). Currently, many security systems are being developed through computer-based identification systems, such as the use of cards, passwords and so on. However, human negligence and limitations in remembering combinations and numbers cause difficulty in accessing the door. Apart from that, generally using this method requires physical contact with special devices to collect data, such as fingerprint scanners and palmprint scanners. Therefore, to make it easier for humans in the authentication process, authentication techniques can be designed using accurate biometric technology by utilizing a person's facial characteristics.

Facial recognition is a biometric technology that has the potential to create a strong security system by identifying individuals based on biological characteristics such as fingerprints, eye retina, voice and facial patterns. Facial recognition is widely used in security by identifying individuals based on faces (Rudi Kurniawan, 2019). There are three stages to performing face recognition, namely face detection, feature extraction, and classification. After a facial sample is stored in the system, the identification process divides it into two categories, recognized or unknown. In the facial recognition process, changes in scale, position, lighting, or details and facial expressions will affect the recognition process (A. Ipanhar, 2022).

There has been a lot of previous research on security systems with various authentication methods, including research conducted by Farhan Guido Hayadi (2021), which uses the Local Binary Pattern (LBP) algorithm using a Raspberry Pi integrated with a smartphone via Firebase as an intermediary, it was found that the use of Firebase is less effective because with the increase in the number of devices connected to Firebase, the data queue in Firebase also increases which will increase data delivery delays. Similar research by Rudi Kurniawan (2019) with the eigenface method as a means of real-time facial recognition with an accuracy rate of 72.5%. Another research is Face Recognition with an ESP32-CAM microcontroller integrated with a camera to detect faces. In this system there is no feature that provides a warning to the homeowner. Thus, it does not provide a sense of security to the home owner and cannot identify the perpetrator if a theft has occurred.

The ESP32 CAM is a microcontroller that has WiFi and Bluetooth, as well as an additional 4MB of external RAM. The advantage of the ESP32 CAM is its low price, this board is equipped with a small camera module that can operate independently. ESP32-CAM also has the ability to recognize faces and save facial data into flash memory, which will remain stored even if the ESP32 is turned off. Noerifanza (2022) stated that the ESP32 camera module was chosen as a potential candidate for Object Recognition activities with a detection speed of 3 to 4 seconds per frame. The ESP32 is a series of relatively inexpensive low-power, Wi-Fi and Bluetooth dual-style camera module systems on one board (Jin Zhao-zhao, 2020).

The importance of a security system is as a form of preventing unknown parties who want to steal or violate privacy without the owner's consent, therefore a security system is needed that has the ability to minimize damage to the system, but due to cost constraints due to increasingly sophisticated security systems, the price is higher must be spent by the user will be more expensive. Thus, on the basis of previous research, it is necessary to carry out research on a Home Door Security Design System Based on Face Recognition on ESP32 CAM.

The research entitled "Home Door Security Design System Based on Face Recognition on ESP32 CAM" is proposed by focusing on facial recognition. This research will work on facial recognition by extracting faces that have been detected by the ESP32 CAM using the Haar Cascade Classifier algorithm method. The stages of the proposed method are collecting facial datasets, image training, classification using the Haar Cascade Classifier algorithm, and model evaluation. The Haar Cascade Classifier was chosen in this research because the Haar Cascade Classifier has the advantage of real-time detection and has the advantage of fast computing because the process only depends on the number of image pixels in a square (Suhepy, 2018). This algorithm also has the advantage of using detection features that build images into integral images and uses simple rectangular features called Haar Wavelets. This system will identify registered faces. Then, if an unregistered face is detected by the camera, the system will send a notification in the form of a face image via Telegram notification as a warning to provide a sense of security for the user when outside the home.

2. RESEARCH METHODS

This research was conducted using research and development (R&D) methods. This method is used to produce certain products by testing their effectiveness. The product can be a model, procedure or system. The development research method consists of 2 stages, namely the initial stage and the development stage. The initial stage includes research and information collection (research and information collection) such as measuring needs, literature studies, small-scale research, and considerations in terms of value. The development stage involves creating design concepts through to evaluation. The research flow can be seen in Figure 1 below:

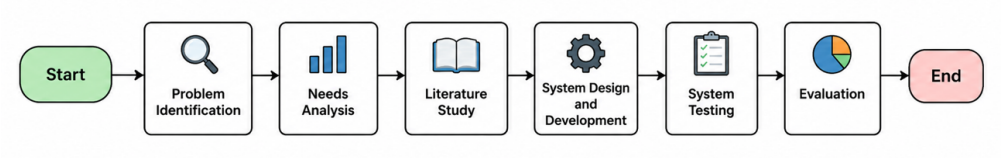

Figure 1. Research Flow

2.1 Potential and problems

The problem that the researcher has previously described is the background and the researcher has formulated it as a basis for the researcher to develop a Home Door Security Design System Based on Face Recognition on ESP32CAM.

2.2 Needs analysis

System requirements analysis is carried out by collecting information and identifying device component requirements by analyzing or detailing the desired features of the components to be used. In this research, this stage is very important to achieve good results.

2.3 Literacy studies

At this stage, a review of relevant literature was carried out from several previous studies. Literature studies function to collect and understand several research references as well as various data and information. This literature study was obtained from books, journals and similar research articles that have been published previously. The purpose of using this literature study is to search for data regarding facial recognition-based home door security design systems and data regarding information related to the design and manufacture of tools.

2.4 System Design and Development

In designing a home door security system based on Face Recognition, researchers first select an application or software that is compatible with the microcontroller, then determine the operating system that can run the application. Next, researchers design the hardware starting by creating a schematic. After the physical form was determined, the design continued by compiling an electronic circuit consisting of several components, including ESP32 Cam as input, Selenoid Door Lock to open and close the door, and Telegram to send notifications regarding the door status. After the hardware design is complete, the next stage is to design the workflow and program logic that will be implemented on the microcontroller.

a. System design design

In this design, face detection is used which is taken via the camera and processed by the ESP32 CAM microcontroller. After the microcontroller processes the detected face, the results are then forwarded to the relay module. The relay module is installed on a 12V DC power source to control the door lock solenoid. The use of a relay module is necessary because the ESP32-CAM microcontroller and door lock solenoid require different power supplies. The hardware design is based on the following system circuit block diagram:

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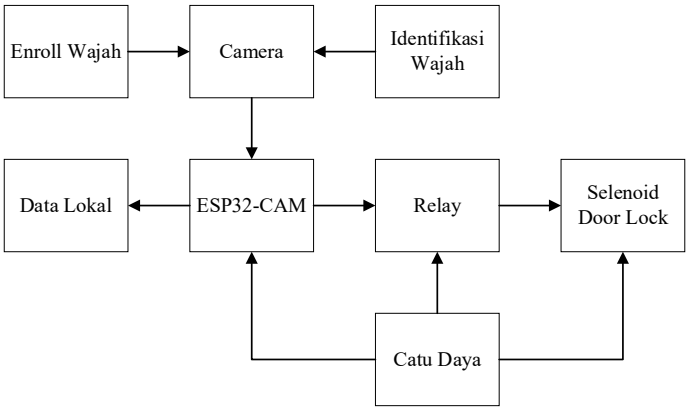

Figure 2. Tool Design Design

b. Whole System Flowchart

In this research, there are stages that will be carried out to create and analyze a home door security system with facial recognition.The process stages start from system initialization ifThe camera will record the face in the form of a video, then forwarded to the processing section and ESP32 CAM will process the data originating from the input using OpenCV and Python using the Haar Cascade Classifier method to match the face, the data that has been processed by the ESP32 CAM will be forwarded to Telegram in the form of a notification of which users have been successfully detected by the camera. The following is a research flow diagram as shown in the image below.

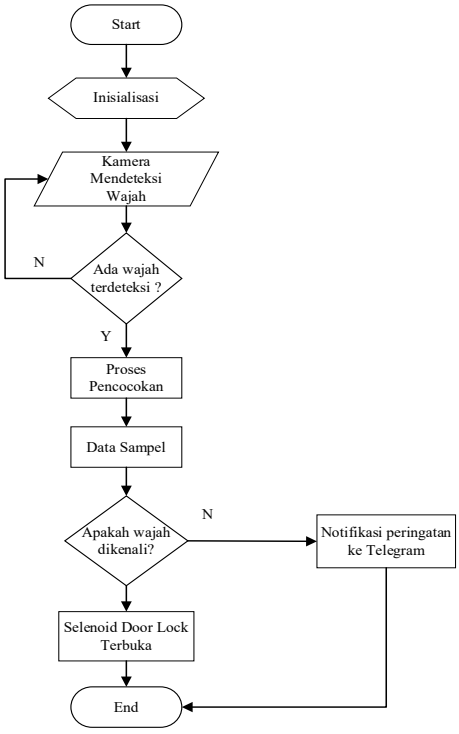

Figure 3. Entire System

c. Face Recognition Flowchart

The system starts by taking or cutting the face from the original image (sub image). Determine haar features by carrying out training first to determine whether there is an object or not in each frame that is processed by subtracting the average pixel in the dark area from the average pixel in the light. Then, an integral image process is carried out in which each pixel value in the image is calculated as the sum of the pixel values in the top left corner to the bottom right corner. When the difference value exceeds a threshold, it can be concluded that there

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are or are not hundreds of Haar features in the image and this can be done efficiently at various scales. The use of integral images allows easy pixel calculations at low cost, by calculating the total number of pixels included in the Haar feature window boundaries, as well as using mirroring techniques to distribute the cumulative function. The next step is cascade, where the greatest weight is placed on the initial stages of this process with the aim of rejecting images that are not faces as quickly as possible.

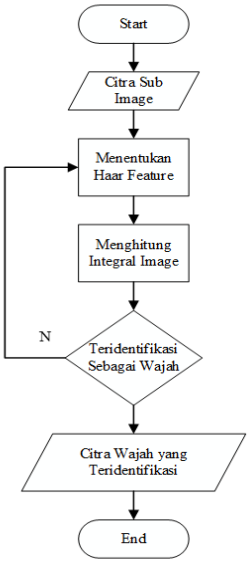

Figure 4. Face Recognition Flowchart

d. System architecture

The system architecture explains that the Home Door Security design system based on Face Recognition was built using ESP32-CAM as the main controller for data traffic that occurs in the system. The camera module used is the OV2640 type to detect and recognize the user's face, which is then forwarded to the relay module. The relay module functions as an automatic voltage breaker in the system. Then the relay carries out commands to the selenoid. The function of the solenoid is to close and open the doors in the system. If the face is not recognized, it will then be sent to the Telegram application connected to the internet connection as a warning notification to the occupants of the house that someone is trying to access the door.

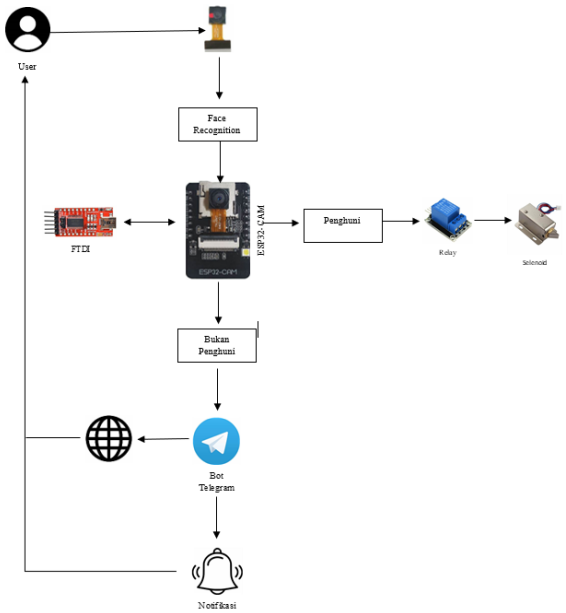

Figure 5. System Architecture

e. Revision

Based on the conclusion of testing the entire tool system, this stage includes adjustments and repairs if there are system errors or incompatibilities that result in the tool not functioning properly as previously explained. Revisionimportant to measure model performance and determine next steps. Revisions help us understand how the model is performing and enable us to take appropriate actions to improve results. If the research results are far from expectations, it is necessary to repeat the process with different methods, but similar steps, to achieve better results.

3. RESULTS AND DISCUSSION

The research carried out was in the form of a Home Door Security Design System Based on Face Recognition on ESP32 CAM.This researchusing the Haar Cascade Classifier method, which is supported by OpenCV. The research process begins with data collection, training, and face detection trials carried out in real time. The input of this system is the ESP32 CAM, which functions to detect, recognize and differentiate between the faces of house residents and non-house residents. The tests carried out are by testing the system on the influence of facial position, testing recognition of other objects, testing face detection and recognition based on the distance between the face and camera. If your face has been verified by the system, the door lock will open. The advantage of a Face Recognition-based home door security system is that the system can send notifications to the home owner if someone accesses the door via the Telegram application.

3.1 Hardware testing

The test results carried out by the ESP32 CAM module when connected using WiFi can function well. In camera testing, the camera also succeeded in taking and processing images quite well. Testing on door lock solenoids aims to ensure that the device functions correctly and reliably in door locking and opening situations when a recognized face is present. When the system successfully detects a face, the solenoid will open with an average time of 1.22 seconds, and then lock again within 5 seconds after the face is detected.

3.2 Software testing

a. Facial recognition testing

This test was carried out on each face with 10 trials per face. The test was carried out with the aim of seeing whether the system could detect faces well or not.

$$Success\ Rate = \frac{The\ amount\ of\ data\ is\ appropriate}{Sum\ of\ all\ data} \times 100\%$$

$$= \frac{24}{38} \times 100\%$$

$$= 80$$

b. Testing variations in facial position

This test is carried out to determine and measure different facial positions and expressions so that you can access the system to carry out facial recognition and open doors. Facial position testing data is shown in table 1.

Table1. Results of testing variations in facial position

Face Position	Test Results
Face facing forward without expression	Detected
Face facing forward with eyes closed	Detected
Face facing forward with a smiling expression	Detected
Face facing left	Not detected
Face facing right	Not detected

c. Distance variation testing

This test is carried out to determine the distance limit at which the door will open. Distance test data is shown in table 2.

Table2. Distance variation test results

Distance Variation (cm)	Test Results
10	Not detected
15	Not detected
20	Not detected
25	Detected
30	Detected
35	Detected
40	Detected
45	Detected
50	Detected
55	Detected
60	Not detected

d. Testing lighting variations

This test is carried out using a lux meter to determine the light intensity value needed for the tool to determine the most accurate lighting to match faces for detection.

Table3. Test results of lighting variations

Light variations	No	Incentiveness of Light (lux)	Test Results
Highlights	1	450	Detected
	2	362	Detected
	3	247	Detected
	4	204	Detected
	5	182	Detected
Lowlights	1	127	Detected
	2	110	Detected
	3	83	Detected
	4	50	Not detected
	5	41	Not detected

e. Testing the image on the photo

Testing by manipulating photos aims to determine the system's ability to recognize faces using photos of previously registered users' faces. Detection is carried out by placing the user's photo for the scanning process. The results of this test show that the system can recognize registered faces using photos, the match percentage can reach 70% but it takes quite a long time for the solenoid to open.

f. Testing on animal faces

This test is carried out by testing objects other than humans. This test aims to find out whether the system can recognize animal facial structures. Based on the results of facial detection tests on animals, it shows that the system is unable to detect the animal's face, even though the test above was also carried out on animals whose facial shape resembles humans, namely chimpanzees. This is becauselibraries and trained faces do not match animal faces, humans also have very striking differences in the characteristics of their facial images compared to animals, such as the dominance of brightness of skin color, shape of facial components and facial texture.

g. Testing sending telegram data

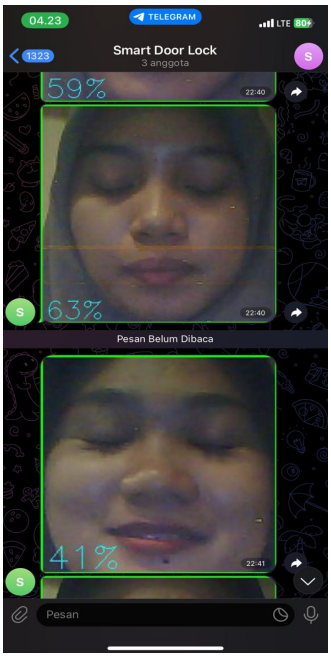

Figure 6. Test results for sending image notifications on Telegram

Testing sending data to Telegram aims to measure the delay time required by the ESP32 CAM to send data. This testing process includes an evaluation of the tool's overall performance, from face detection to sending data to Telegram. The system successfully sent facial data that was not registered in the database as an unrecognized face. By using a predetermined formula, the system success rate reaches 100%. In sending data, the delay time from the detection process until the image data is received by Telegram varies, with the longest time being 8.20 seconds and the fastest time being 4.60 seconds. This difference is caused by the initial system process which involves training and saving data to the library as well as differences in time in the matching process which is influenced by image resolution.

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the research, the house door security system based on face recognition using ESP32-CAM was successfully designed and implemented. The system uses the Haar Cascade algorithm to detect and recognize faces, and the test results show that it can distinguish between faces registered in the database and unregistered faces or other objects. The functionality testing also indicates that the main components of the system, including the WiFi connection, camera image processing, and overall device performance, work properly and according to the planned design. In the face recognition process, several factors significantly influence detection performance, including the distance between the face and the camera, lighting conditions, face position, facial expressions, and the clarity of the facial image captured by the ESP32-CAM. The system achieved an accuracy of 80% in matching facial images with the database. For future research, it is recommended to use a face recognition algorithm with a higher level of accuracy, apply a camera with better specifications, and add more advanced features that are aligned with user needs and current technological developments.

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