Enhancing Electric Vehicle Security with Face Recognition: Implementation Using Raspberry Pi

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***Abstract*—Facial identification has emerged as a key research area due to its potential to enhance biometric security. This research proposes an advanced security system for electric vehicles (EVs) based on facial identification, implemented using Raspberry Pi. The system comprises two main modules: Face Detection and Face Recognition. For face detection, the researchers propose using the Viola-Jones algorithm, which leverages Haar-like features to detect and extract unique facial features, such as the eyes, nose, and mouth. MATLAB will be used as the development tool for this module. For face recognition, the proposed approach integrates Principal Component Analysis (PCA) with Support Vector Machine (SVM). PCA is used to extract the most relevant facial information and construct a computational model, while SVM enhances classification accuracy. The system's performance is evaluated using accuracy and the Receiver Operating Characteristic (ROC) curve, with results demonstrating a face recognition accuracy of 95% and an average execution time of 2.32 seconds, meeting real-time operational requirements. These findings confirm the proposed method's reliability in offering advanced and efficient biometric protection for modern electric vehicles.**

***Keywords*—Face recognition; face detection; Principal Component Analysis (PCA); Support Vector Machine (SVM); Raspberry Pi**

I. Introduction

In this era of globalization, the rapid growth of modern electrical vehicles (EV) with advanced technologies requires strong security to prevent customer's vehicle begin stolen. Passive Entry Passive Start (PEPS) was introduced to enhance the security of EV by using low-frequency (typically 125 kHz) or ultra-high-frequency signals to exchange unique key access codes between the key and the vehicle. When these codes match and yield the expected value, and the key is within the vehicle's range, the car grants access to the driver [1], [2].

However, the low-frequency or ultra-high-frequency signals can be easily duplicated or coped using a specific hacking device tool especially in this modern era [3]. This situation leads to the risk of EV being stolen.

Therefore, it is necessary to develop a security system to enhance the security of EV. One of the ways is to integrate the EV with biometric which is using facial recognition.

Biometrics are becoming increasingly integral to both personal security setups, providing a strengthen layer of protection. Biometrics use unique body features, such as fingerprints, irises, and facial structures, to authorize access. Thus, one of the biometrics was facial recognition technology. In 1967, Woodrow W. Biedsoe, a pioneer in artificial intelligence, developed a system that can classify photos of face using a graphical computer input device known as RAND tablet. The exponential growth of technology makes facial recognition integral with complex algorithm artificial intelligence, neural network, and machine learning to process, identity, and classify images with a high degree of accuracy.

The problem statement for developing facial recognition using Raspberry Pi module on electrical vehicle (EV) is because there is an increasing number of consumers buying EV as the prices are affordable. However, the EV nowadays uses passive entry passive start (PEPS) system to allow driver access into the vehicle. By using this PEPS system, drivers need to carry the key to unlock their EV. The disadvantage of this system is that driver might lose their key due to the careless behavior causing them need to pay expensive price to replace the key. Furthermore, some EV store their unique code in remote control and driver need to carry it and present in the range of the EV in order to access it, but sometimes the battery of the remote control drain out due to long time in use or the remote control suddenly malfunction. If the key is stolen, the EV can be accessed by who is holding the key.

Given the vulnerabilities of current Passive Entry Passive Start (PEPS) systems and the rising demand for secure keyless access in electric vehicles, it is crucial to explore biometric alternatives that offer both accuracy and reliability. This study seeks to answer the following research question: Can a facial recognition system implemented on a Raspberry Pi using PCA and SVM provide secure and efficient keyless access to electric vehicles while maintaining high accuracy and real-time performance? By addressing this question, the study aims to bridge the gap between low-cost embedded systems and advanced biometric security solutions for EVs.

The solution that is proposed in this project is to implement facial recognition in EV using Raspberry Pi. The Raspberry Pi module is a microcontroller that can configure based on desire function using programming. The module will integrate with other components such as camera, lock of EV, and engine of EV. The system will provide an interface for driver to use facial recognition to access their EV.

The system of facial recognition in EV will solve the problems of the present EV limited access option and give flexibility. Drivers will be able to access their EV using their facial feature without carrying any key on them. The security system using facial recognition on EV will improve driver experience and simplify the process of unlock EV. The objective for the development of facial recognition in electrical vehicles using Raspberry Pi is to achieve more than 95% accuracy of facial recognition and achieve execution time not more than 3 seconds. To analyze the accuracy and efficiency of the facial recognition system using Receiver Operating curve, and to develop a facial recognition system to access EV with Raspberry Pi. The first step of this project is to create a block diagram to illustrate the facial recognition system in EV. After that, selecting the proper version of microcontroller, sensor, actuator, and other components. The microcontroller will need to program to recognize a person's facial feature and record it into its database then allow access to an authorized person. The microcontroller also needs to control other components such as lock and motor. Decentralized coordination concepts, such as those used in multiarea temperature control systems, can enhance the modular management of EV subsystems [4].

High quality camera module is required in the procedure of facial recognition because it is used to take input (image) from driver. The facial recognition system in EV needs to be programmed using specific algorithm. Thus, a user interface will be necessary for programming and allow users to interact with the system to set up their biometric. Meanwhile, the security system might need to be improved soon. Thus, this requires an LCD panel and a keypad or touch screen panel. In a word, developing a microcontroller-based security system that uses facial recognition in EV required various knowledge, such as microcontroller programming, technical skills, and logic thinking. Iterative design approaches and formal validation techniques, such as model checking, can further enhance the reliability of embedded authentication systems in critical applications [5]. Implementing face detection and recognition technology for unlocking electrical vehicles (EV) has several societal implications. In a word, this technology not only brings convenience it also enhances the security for users. It makes the process of accessing vehicle more simple and easy, reduces the risk of theft, and potentially minimize the chance of losing physical keys. However, societal concerns arise regarding privacy and surveillance. Implementing facial recognition technology may lead to an increase in potential infringing on individual privacy rights. This is because users were concerned about who has access to the facial data and how it is stored.

In terms of health perspective, facial recognition technology may affect user's psychology due to the reason of continuing monitoring by the technology system. Indirectly, this can lead to stress and anxiety among users. The facial recognition in EV must be very sensitive and accurate in detecting user's face to avoid potential safety hazards. It is equally important to address functional safety in the communication layers, especially when facial data is transmitted over embedded networks [6].

System malfunction or misrecognition could lead to unauthorized access or system lock users out of their vehicles. Thus, reliability and accuracy of the facial recognition technology must be considered first before implementing the EV. When it comes into legal issues, engineers must ensure that their systems obey with local, national, and international laws regarding data protection and privacy. Issues such as data permission, storage, and sharing must be addressed in compliance with legal standards. Furthermore, there could be legal liabilities in case of system failures or breaches that lead to unauthorized access or harm. In some cultures, there is a high acceptance and trust in technology. Meanwhile, there is controversy and concern about privacy and surveillance. Engineers must consider these culture differences when designing and implementing facial recognition systems. One of the ways to address these issues is to carry out a survey with communities to understand their concern.

The main contributions of this research are as follows:

- The study implements a face detection and recognition system to enhance biometric security in electric vehicles.
- The proposed system integrates Principal Component Analysis (PCA) with Support Vector Machine (SVM) to improve facial recognition accuracy.
- A real-time face recognition system is deployed on a Raspberry Pi platform, ensuring a cost-effective and efficient security solution.
- The performance of the proposed system is evaluated using accuracy metrics and the Receiver Operating Characteristic (ROC) curve, achieving 95% recognition accuracy.
- The system offers a keyless vehicle access mechanism, improving user convenience while mitigating the risks of key theft and duplication.

The paper proceeds as follows: Section II reviews existing methods relevant to the current study. The proposed approach is presented in Section III. Section IV presents the experimental results, while Section V discusses the findings in detail. Section VI outlines the conclusions drawn from the study, and Section VII highlights the limitations and proposes potential directions for future work.

II. Literature Review

A literature review is a critical overview and assessment of the body of work such as books, academic articles, dissertations, or conference papers that have already been published regarding a specific subject or research question. It involves reviewing, assessing, combining relevant materials to present a summary of the state of knowledge in a specific field or topic area. In this chapter, reviews on explanation on algorithm used, past studied, and project regarding the implementation of Facial Detection and Facial Recognition and all its component that will be explained.

In this study [7], the author has shown that there are three important stages in the structure of Face Recognition to produce a robust system. The first stage was face detection and obtain input either in image or video to locate the position of human face. Secondly, the feature extraction was the stage to extract the unique feature of human face such as eyes, nose, mouth, and mustache for any human faces located in the first stage. Lastly, the stage of face recognition uses the features extracted from the human face to compare it with all templates faces in database to decide the human identity. Fig. 1 shows the structure of face recognition by [8].

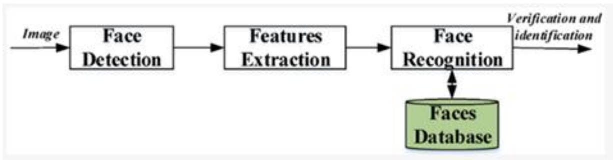

Fig. 1. Structure of face recognition.

A. Face Detection

Face detection is an algorithm used to detect the presence of a human face, serving as a crucial preprocessing step for face recognition [9]. The system will create a box bounding if the human face is in detection, the box will be in green color [10]. One of the most famous algorithms used in face detection was Viola Jones's algorithm, known as Haar-Cascade algorithm.

B. Haar-Cascade algorithm (Viola Jones's algorithm)

The algorithm was proposed by Viola and Jones in 2001. The algorithm is used in various applications that apply face detection because it can recognize faces in a real time video [11]. Human's facial features can be differentiated from a set of data image by using Haar feature. Haar features were proposed by Alfred Haar in 1909. The detector of cascade detects the face in the captured mage or real-time and face region is extracted. The face image was normalizing to remove the noise or unwanted information due to other factors while capturing the image [12].

C. Face Recognition

Face recognition is a process of identifying or giving access to an individual using their face without physical contact with any hardware. Sun and Chen [13], originally proposed a method for face recognition. Today, this approach is widely used in modern systems. Face recognition is mostly used to identify people in photos, videos, or in real-time. In nowadays, the accuracy of face recognition system can be improved using machine learning, the system is trained using images of authorized users, and the accuracy of recognition can be enhanced [14].

D. Principal Component Analysis (PCA)

PCA was proposed in 1901 by Karl Pearson, who introduced the idea and implemented it to non-random variables [15]. Harold Hoteling extends the concept of Karl Pearson to random variable in 1930. Nowadays the technique is applied in various fields, including mechanics, economics, medicine, and neuroscience. In computer science, PCA is used as a tool for data dimensionality lowering. In the era of Big Data, the data we process was large and complicated. Thus, PCA can reduce computational complexity and save computer storage. Next, face recognition benchmarks that used PCA have been achieved using machine learning and are applied in research and commercial application [16].

E. Support Vector Machine (SVM)

SVM is an algorithm that was developed in 1990 by Vladimir N. Vapnik and his team [17]. SVM was mostly used in classification problems. The algorithm was recommended in solving binary classification. SVM can differentiate between two classes by calculating the optimal hyperplane that maximizes the margin between the closet data points of opposite classes. Furthermore, SVM can be categorized as a supervised deep learning algorithm, which is frequently used in the process of classification models and regression problems. Recent studies have also demonstrated the potential of SVM for secure, real-time decision-making in intelligent systems, including blockchain-based environments in the Internet of Medical Things (IoMT) [18].

F. Related Works

In this research paper of using Facial detection and Facial recognition in EV using Raspberry Pi, the important key in this system was the algorithm that implement. Thus, researchers have reviewed several papers that propose different algorithms for face detection and face recognition. One of the papers by Khairul Anuar Ishak [19], presents a system using face detection and face recognition to unlock the door and ignite the engine of vehicle, the algorithm they used for face detection was the combination of Fast Neural Network and Convolution Neural Network while the algorithm used for face recognition was the combination of Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA). The study of the paper aim to improve the accuracy of face detection and face recognition when drivers want to access the vehicle. The combination of the algorithm used in the system shows the highest recognition rate and lowest misclassification rate. The system proposed in this research paper shows the total processing time for driver access to a vehicle with 5.1 seconds and the average recognition rate of 91.43%.

Another research paper by SL LIN and JY WU [20], the facial recognition system used FlagBlock building block program software of Flag Maker. The program creates a website for browser connections to use facial recognition, so that the user can get output and input of the information of D1mini. The author used mobile phone or computer browser as D1mini output interface. Principal Component Analysis (PCA) as the algorithm for analysis through the experiment, two-dimensional PCA was chosen by the author and found out that recognition correctness showed good results compared to the rate of accuracy of original image. 300 face photos were used for training for PCA analysis, and the test was carried out 100 times. The results for recognition rate were 92%. The success rate was dependent on the situations, such as lighting conditions, distance, and the angle of the face.

Next, authors Chaitanya Kolluru, Akhil GV and their colleague propose a research paper "Development of Face Recognition-Based Smart Door Lock System with Remote Servo Control Authentication" [21]. The proposed project used Haar-Cascade for the face detection, OpenCV library was used for image processing to detect the multiple faces. Then the author integrates the system with AdaBoost machine learning, the machine learning chooses the most relevant Haar-like features from a large number of features. The author used Dlib's algorithm for facial recognition, the algorithm uses deep metric learning by using a neural network called Reset. This method learns a mapping from face image to a high dimensional feature space because some faces will have same feature from different people. The system used Raspberry Pi board with a camera module, Motion sensor responsible for motion detection during low-light condition while the servo motor control for door lock. The proposed system achieved 92.72 % of accuracy when the system was trained with 1000 image and achieve 80.24% accuracy rate in low light.

In [22], the research paper proposed a system to ignite vehicle using facial recognition. The system used Convolution Neural Network (CNN) models as the machine learning for to recognize the authorize person. During the training session, author choose four different people as input image for CNN models, each person has 500 of image. The backbone of the CNN model used for facial recognition have four layers and it will produce stage by stage using the same layer. The first layer was the input layer, this layer carried out images from the pre-processing stage. The second layer was the three stages of convolution layers, each consisting of a convolution operation and a rectified linear unit (Relu). The third layer implemented fully connected layer. The final layer was a dropout layer, utilizing four classes of face images in CNN model for facial recognition. The proposed model has achieved 98.3% of accuracy for face recognition.

The purpose of the project is to enhance the security of the vehicle by using face recognition to ignite the car's engine. The proposed system uses cascade detectors that recognizes the obtaining image and extract the feature of the face region. OpenCV was used for face recognition operation, the operation was done using variety of algorithm, including feature-based and model-based algorithm. The research paper stated that LDA (Linear Discriminant Analysis (LDA)) was better than PCA (Principal Component Analysis) when big training sets was applied in recognition. The accuracy of the proposed system achieved more than 80% when come into confirming the identity of user with the saved image of user in the system [23].

In this research paper [24], author has made an evaluation of the performance of facial recognition model based on multiple algorithms. Algorithms which are used were Support Vector machine (SVM), Local Binary Patterns Histogram (LBPH), Eigen faces (EF), Principal Component Analysis (PCA), and Linear Discriminant Analysis (LDA). The datasets used for the training was from ImageNet and Scikit Learn tool and was used to determine the accuracy, precision, recall, F1-Score and execution time for each method. The execution time for each algorithm can be rated as PCA<SVM<LBPH<LDA<EF. However, from the perspective of precision and accuracy of the algorithms, SVM performs better than another algorithm which are 98% for both perspective.

On the other research paper [25] by Asif Rahim and his team, they enhance the performance of face detection and facial recognition in smart home system by using logistic regression (LR), Hist gradient-boosting classifier (GBCs), and convolutional neural network. The reason for authors to enhance the system was because, the factors of illumination condition, facial expression, pose, occlusions and aging pose affected the accuracy of face recognition. The proposed models also compare with LR-XGB (XGBoost)-CNN, LR-CBC (CatBoost Classifier)-CNN, LR-GBC (GradientBoost)-CNN, LR-ABC(AdaBoost Classifier)-CNN, and LR-LGBM(LightGBM classifier)-CNN, and were evaluated based on their functionality using a dataset containing sensor readings and face images. Among these, the LR-HGBC-CNN model has shown a good results compared with other model because it achieved high scores across multiple metrics such as accuracy, precision, recall, F1 score, and AUC-ROC in both anomaly detection and facial recognition tasks. Specifically, the LR-HGBC-CNN model reached an accuracy of 94% for anomaly detection and 88% for facial recognition, indicating its robust capability in distinguishing normal and abnormal events as well as recognizing authorized faces in smart home environments.

In this research paper [26], the author develops a hardware that can capture image of kidnapper and perform face recognition on the suspect to help victims' family to rescue their children in shortest period. The face detection method used by the author was Viola-Jones algorithm. The author used Convolution Neural Network (CNN) to perform the facial recognition system [27]. The dataset that was used by author was AT&T database, Celab Faces Attributes dataset, and face dataset that are collected by author and the outcomes are 87.50%, 92.19% and 95.93% respectively. Overall face recognition accuracy was 98.48%.

In [28], author had demonstrated the face recognition using algorithm Local Binary Pattern Histogram (LBPH). The objective of the study was to produce a biometric security system for better function. The biometric system was integrated with augmented reality (AR) and the face recognition rate was achieved at 90% in bright lighting conditions.

In this research paper [29], the study focuses on developing a system that can process fast face recognition so that it can monitor student attendance in smart classroom. The proposed method based on Convolution Neural Network (CNN) and able to detect 30 faces out of 35 detected faces [30]. They use Edge Computing for processing the data at the edges of the nodes to reduce the data latency and enhance the real time response. Their proposed system had made accuracy of 85.5% in face recognition and 94.6 % in face detection.

From [31], author had developed a face recognition for absence information system. The study stated that the face recognition system can apply Principal Component Analysis (PCA) and Support Vector Machine (SVM). The author used customize dataset which is 100 facial data for test data and training data. The system test results showed that the use of PCA and SVM as a classifier can achieve a high level of correctness. The training included the facial image, 91% of the identification was correct.

While numerous studies have explored face recognition using PCA, LDA, CNN, and other algorithms, most have focused on controlled environments or high-performance computing platforms. Few have investigated the feasibility of integrating PCA and SVM for real-time face recognition on embedded, low-cost platforms such as Raspberry Pi [32], [33]. Additionally, although prior works achieved recognition accuracies ranging between 85% to 92%, there is a lack of comprehensive evaluations that simultaneously address execution time and recognition accuracy in EV security contexts. This study aims to fill this gap by implementing and evaluating a PCA + SVM-based face recognition model on Raspberry Pi, emphasizing both security performance and real-time responsiveness, specifically for EV access systems.

III. Proposed Method

To develop a system that can recognize human facial using Raspberry Pi module, a hardware device such as Raspberry Pi 4 module, is used to capture the face image of the authorize person, which serve as input image to the facial recognition. A custom face dataset is necessary for training and testing the correctness of the proposal system. The components used for the hardware are the Raspberry pi 4 module, LED light, PIR Motion Sensor, Camera Pi module, breadboard, Lan cable, and power adapter [34]. To make the Raspberry Pi as a standalone hardware for face recognition system, MATLAB software is used for deep learning in facial detection and facial recognition [35]. After the accuracy of the system is reached as our objective which is to achieve more than 95%, the program will be deployed to the Raspberry Pi board through LAN cable. Fig. 2 shows the block diagram of the system. Several studies have explored similar microcontroller-based integrations using ESP32, ESP8266, and Arduino platforms for IoT and control applications [36], [37] and [38], validating their effectiveness in real-time monitoring and system automation.

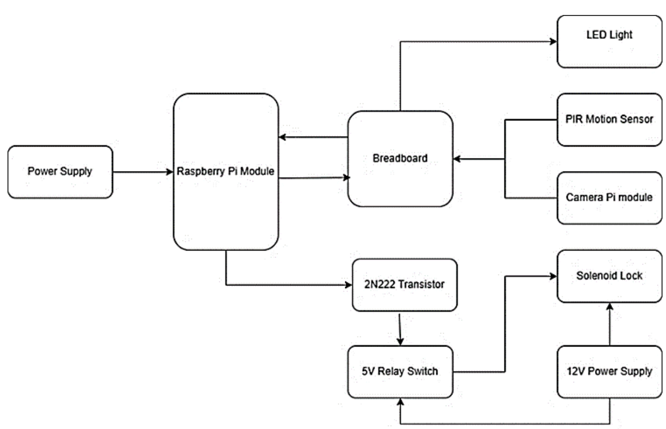

Fig. 2. Raspberry Pi face recognition block diagram.

A. Programming Flowchart

Based on Fig. 3, the flowchart shows a person's facial feature is set and recorded as a template in the database before the face recognition process start. The system (Raspberry Pi) was powered by a 5V direct current and will always be in the standby mode. The motion sensor will detect the presence of human and turn on the system, the system starts detecting and isolate a human face in a rectangle that indicate the region of interest. After that the camera will capture the image through the camera module (Raspberry Pi Camera module) [39]. If fail to capture the human's face the system will deny the access. After the capturing is successful, the captured human's face will be compared to the face template that is set on the database. After that, the system would make decision, if the face matched with the face template in the database, then the access will be granted. However, for the unmatched face, the system will show a message "Access Denied".

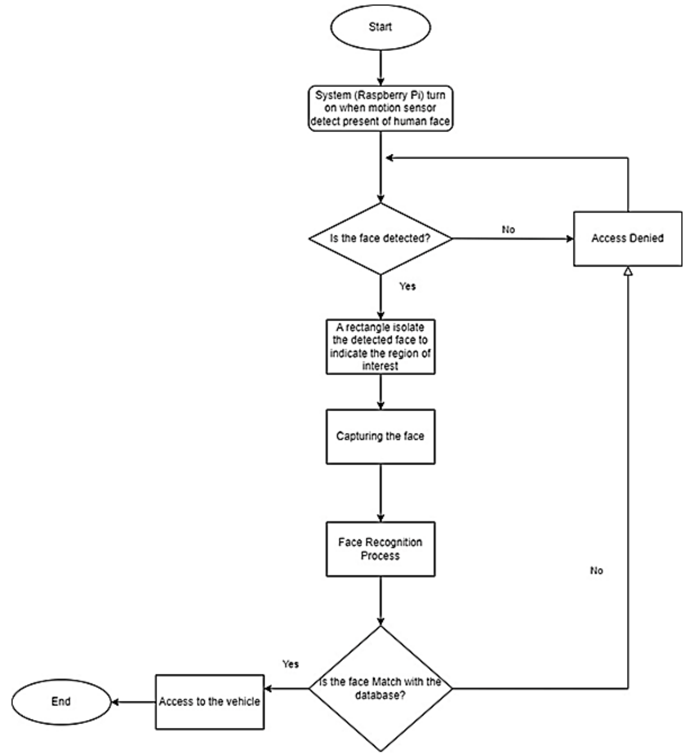

Fig. 3. Programming flowchart.

B. Dataset

A dataset is important for face recognition system. When it comes to stage for testing the accuracy of the algorithm, a quality dataset ensures that the algorithm is able to differentiate one face from another. This includes understanding in facial features, angle, and lighting conditions. When an algorithm was trained and achieve high accuracy of face recognition, meaning it can accurately recognize faces it has never seen before by using the general features of human faces. To achieve high accuracy of face recognition. Researchers use AT&T dataset which consists of 400 human faces and a custom set of databases which consists of 200 human faces to test the system efficiency.

C. Algorithm

The method used to design the proposed work was the combination of Principal Component Analysis and Support Vector Machine (SVM) to develop a facial recognition system. Viola- Jones's algorithm is vital in the face recognition as it is the first step in face recognition. This algorithm developed for general object detection, and it can be trained to an algorithm that can detect human face only. According to [40], there are four main steps in Viola- Jones's algorithm which were Choosing Haar-like features, creating an integral image, Running Adaboost training, and Creating classifier cascade. An input data (image) is segmented into tiny of size NxN and convert into rectangle area and features are calculating individually every single rectangle. Human face have shared some similarities, for an instance, the nose region tends to be brighter than the mouth region and the eye region are typically darker compared to the forehead. Fig. 4 shown the basic Haar-like Rectangle features.

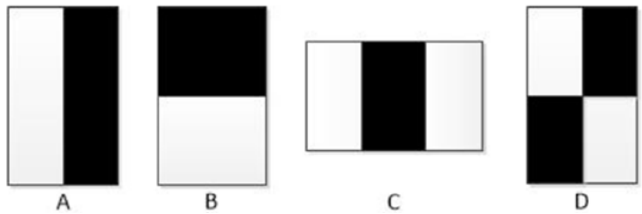

Fig. 4. Basic Haar-like rectangle features.

Haar-like features are efficiently calculated apply an intermediate representation known as the integral image, which accelerates computation. In Eq. (1), it computes the integral images. Total of the pixels above and left of (x, y) was included in the integral image which locate at x, y.

$$(x, y) = \sum_{s=1}^{x}\sum_{t=1}^{y} I(s,t); 1 \leq x \leq M, 1 \leq y \leq M \quad (1)$$

The integral image was represented as 'A' as shown in Fig. 5. The original image is represented by 'I'. The rectangular region represents as 'M'. The integral image at location 1 in Fig. 5 equals to the total of the region 'A'; while in location 2, A+B is the sum of pixels in region; the total pixel in region C+A was located at location 3; lastly, the summation of the pixel in the region A+B+C+D is locating at location 4.

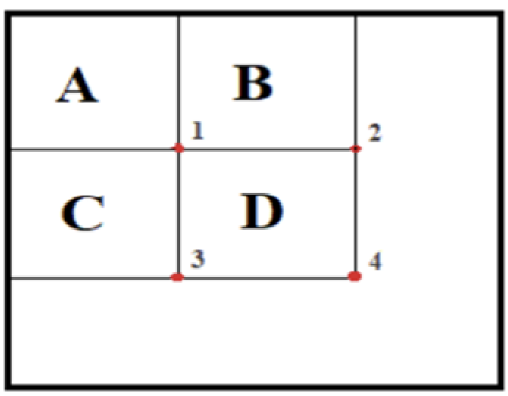

Fig. 5. Integral image formation.

Adaboost algorithm used to reduce the redundancy because the Haar features calculate in every single window is very huge (estimate 180000). The majority of the features are unnecessary. Cascading classifiers [41] will reduce the number of calculated images and selecting the perfect features in every window. PCA is utilized to extract features from the segmented images, serving as the basis for the recognition process by preserving essential information while reducing data dimensionality. To enhance the recognition technology's performance, a beta prior is incorporated, and a full-probability Bayesian model is developed, offering an improvement over the conventional PCA approach. Face recognition technology, as a biometric identification method, leverages computer vision to analyze facial images and identify key feature points such as the eyes, nose, and mouth. Fig. 6 shows the steps for cascaded classification by stages [42].

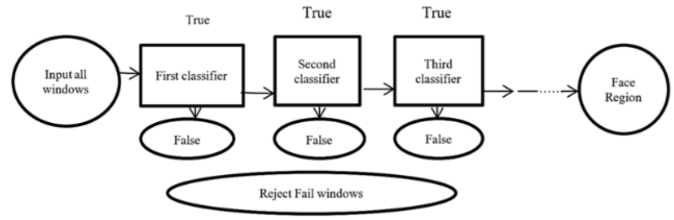

Fig. 6. Steps for cascaded classification by stages.

There are three formulas, Eq. (1), Eq. (2), Eq. (3) used in Principal Component Analysis which were mean, standard deviation and variance.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (2)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - mean)}{n-1}} \quad (3)$$

While the data is often multi-dimensional in computer science. The relationship between two random variables can be described through covariance, Eq. (4):

$$cov(X,Y) = \frac{\sum_{i=1}^{n} X_i - mean\ of\ X(Y_i - mean\ of\ Y)}{n-1} \quad (4)$$

Multiple covariance needs to be calculated as Eq. (5) as the dimension increases. For example, the quantity of covariances required for handling n-dimensionally data:

$$\frac{n!}{(n-2)! * 2} \quad (5)$$

Eq. (6) shows the matrix methos give a solution for this solution:

$$C_{n*n} = \left(c_{i.j}, c_{i.j} = cov(Dim_i, Dim_i)\right) \quad (6)$$

Covariance matrix, Eq. (7) was a dataset in three dimensions {x, y, z}:

$$C = \begin{pmatrix} cov(x,x) & cov(x,y) & cov(x,z) \\ cov(y,x) & cov(y,y) & cov(y,z) \\ cov(z,x) & cov(z,y) & cov(z,z) \end{pmatrix} \quad (7)$$

It can be observed that the covariance matrix is a symmetric matrix because the diagonal shows the variance of each dimension. After obtaining the covariance matrix, eigenvalues and eigenvector can be calculated using Eq. (8):

$$A\alpha = \lambda\alpha \quad (8)$$

'A' stands for the original matrix while λ stands for an eigenvalue of A, and α represents the eigenvector according to eigenvalue λ. The study in [43] shows two stages in face recognition using Principal Component Analysis which are training stage and testing stage.

In [44], [45] and [46], Support Vector Machine (SVM) method in machine learning, valued for its capability to handle high-dimensional data and its robustness against noise. Praised for its ability to manage high-dimensional data and its resilience to noise. In the context of a set of training data (Xi, yi), where, Xi represents the feature vectors and yi denotes the class labels, the purpose of SVM is to determine the optimal hyperplane. Below is shown the Eq. (9):

$$W^T x + b = 0 \quad (9)$$

W represents the impact vector, x denotes the input feature vector, b is the bias term. This purpose is to maximize the margin between the hyperplane and the support vector, which are the closet points to the hyperplane form both classes. The optimization problem can be formulated as Eq. (10):

$$\min(w, b)\frac{1}{2}||w||^2 \quad (10)$$

Subject to Eq. (11):

$$y_i(w^T x_i + b) \geq 1 \quad (11)$$

The accuracy of the proposed work can be measured by using the formula, Eq. (12) by [47], [48] which were using True positive, True Negative, False Positive, and False Negative:

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN} * 100\% \quad (12)$$

ROC curve represents the curve of sensitivity (True positive rate) against 1-specificity (False Positive Rate) while varying the threshold. Different cut-off points are responsible for generating this graph. The AUC (area under the curve) quantifies the effectiveness across various test thresholds on the ROC curve. Fig. 7 shows an example test with an AUC of 1.0 is very accurate as the sensitivity reaches 1.0 while specificity also archives 1.0.

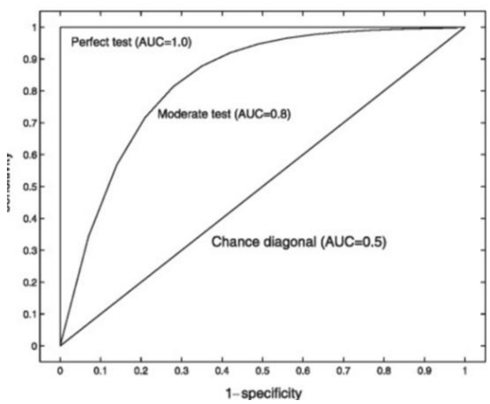

Fig. 7. ROC curve.

D. Circuit Design

Fig. 8 shows the circuit connection between Raspberry Pi module, Relay Switch, 12V battery, Solenoid lock, Pi Camera Module, and PIR sensors. In this project, researchers use Raspberry Pi GPIO pin to communicate with other components. Below Fig. 9 shows the GPIO pin with label for better understanding.

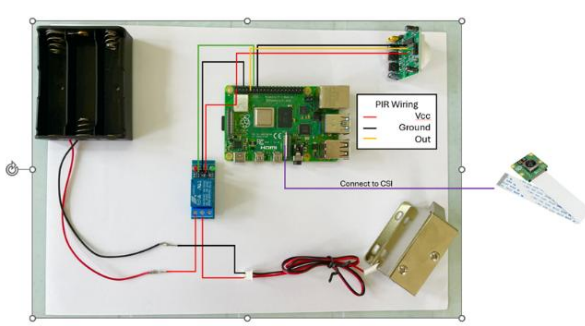

Fig. 8. Circuit design.

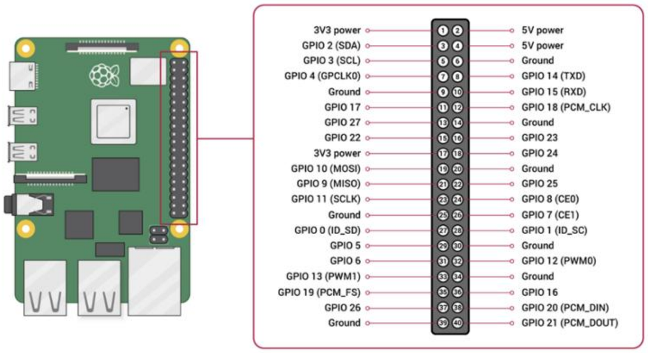

Fig. 9. GPIO pin in Raspberry Pi.

IV. Result

The proposed work starts with testing the algorithm in MATLAB software by using the application of classification learner. The dataset of 10 people was prepared and divided into classes, each class contain 10 images. After that, the dataset was converted into table firm since the classification learner only accept dataset in table form. The classification learner can analyze the reliability of the input dataset by using the algorithm of PCA and SVM. Fig. 10 shows the results of using classification learner to test the input dataset:

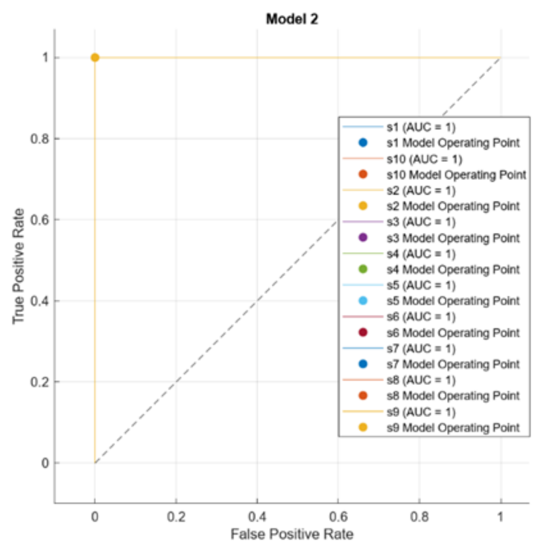

Fig. 10. ROC Curve for 10 people.

From the ROC, each person was named for ‘s’. Thus, there were 10 class, and each class represented a different person. The area under the ROC curve (AUC) represents the probability that the model. From the results, we can conclude that every class where, the area under the curve (AUC) were 1.0, which mean the classifier can perfectly differentiate between positive and negative classes.

A. Test the Custom Face Database with PCA and SVM

The custom face dataset was needed to pre-process by converting the images into table form before the training session. Before converting the images into table form, the dimensions of images were fixed at 180 (width) x 200 (height). The number of components was a crucial step in determining the accuracy of the model. If fewer components were selected it would reduce computational complexity but may lose some information. However, more components retain more information but increase complexity. In this part, researchers used 50 components for 250 images to test the performance of the model. The Fig. 11 shows the accuracy of the training results:

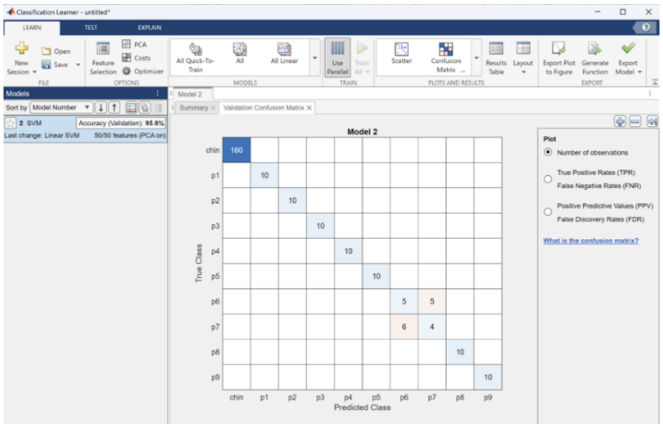

Fig. 11. The Acccuracy using PCA and SVM using 250 images.

To test the accuracy of the proposed face recognition model, the True Positive (TP), True Negative (TN), False Negative (FN), and False Positive (FP) were recorded in Table I. The table shows the value of each class in model training:

TABLE I. FACE RECOGNITION RESULTS OF CUSTOM DATABASE

Class	Testing Images	TP	TN	FN	FP	Accuracy
chin	10	10	0	0	0	100%
P1	10	10	0	0	0	100%
P2	10	10	0	0	0	100%
P3	10	10	0	0	0	100%
P4	10	10	0	0	0	100%
P5	10	10	0	0	0	100%
P6	10	5	3	0	2	80%
P7	10	4	3	1	2	70%
P8	10	10	0	0	0	100%
P9	10	10	0	0	0	100%
	Total	89	6	1	4	-
Average Accuracy						95%

The table presents the classification performance of a model across ten different classes, each with 10 testing images, totaling 90 images. The model achieved perfect accuracy (100%) for most classes, including chin, P1, P2, P3, P4, P5, P8, and P9, correctly identifying all instances. However, performance dropped for P6 and P7, with accuracies of 80% and 70%, respectively, due to false positives and false negatives. The overall accuracy of the model is calculated at 95%, indicating strong general performance. The errors in P6 and P7 suggest potential challenges in distinguishing these classes, which may require further investigation, such as improving feature extraction, enhancing the dataset, or optimizing the model parameters. Expanding the testing dataset could provide additional insights into performance trends and areas for improvement.

The execution time was measured using the average method, where the test was conducted 20 times to ensure consistency and reliability of the results. Table II shows the recorded time and average time for the code execution:

TABLE II. AVERAGE TIME FOR CODE EXECUTION

Test	Time (s)
1	2.32
2	2.45
3	2.37
4	2.32
5	2.54
6	2.29
7	2.29
8	2.29
9	2.28
10	2.30
11	2.31
12	2.27
13	2.28
14	2.33
15	2.31
16	2.38
17	2.39
18	2.30
19	2.28
20	2.28
Average	2.32

B. *Test the Face Recognition with Raspberry Pi*

After the testing had done in MTALAB, the proposed work has been moved into Raspberry Pi to test. When there is presence of face, region of interest (ROI) will isolate the face region and capture the image [49]. The purpose of doing this is to carry out a real time facial recognition in Raspberry Pi to let user unlock the vehicle door. Fig. 12 shown the results of using Raspberry Pi execute the command.

Fig. 12 also shows the results when authorized face was detected. While Fig. 13 shows the results when unauthorized face was detected and 'unknown' was shown in the window screen.

The time for the system detects the face was 2.32 seconds by using the average method to calculate the time. While the accuracy when compared with previous work had shown that the accuracy has been improve using PCA and SVM. Table III shows the comparison of the accuracy.

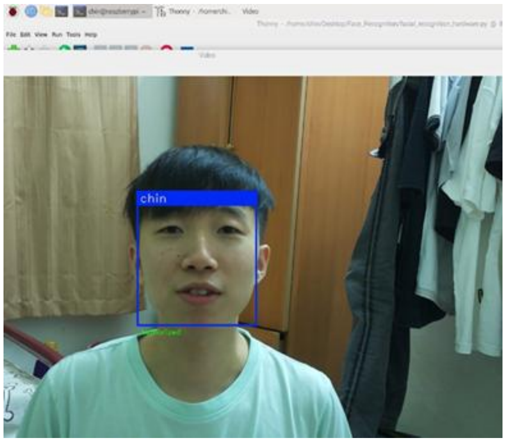

Fig. 12. Face recognize using Raspberry Pi.

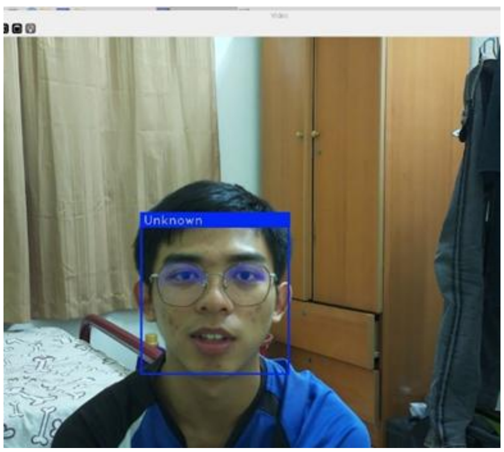

Fig. 13. Unauthorized faces detected.

TABLE III. COMPARISON OF ACCURACY IN FACE RECOGNITION ALGORITHM

Ref.	Algorithms used in Face Recognition	Database	Accuracy (%)
[15]	PCA + LDA	Customize	88.75
[16]	PCA	Customize	92.00
[17]	Haar-Cascade + Dlib's face recognition	Customize	92.72
[20]	PCA +LDA	Customize	80.00
[23]	CNN	AT&T	87.50
[24]	LBPH	Customize	90.00
[25]	CNN	WILDS	85.5
[26]	PCA + SVM	Customize	91.00
Proposed algorithm		Customize	95.00

The accuracy of facial recognition using a different algorithm and database is recorded in Table III. Compared to existing studies, the proposed PCA + SVM-based facial recognition model offers several distinct advantages. First, it achieved the highest recorded accuracy of 95% among all reviewed works, surpassing traditional PCA + LDA, LBPH, CNN, and Dlib-based methods. Second, the model maintained low execution time (2.32 seconds), demonstrating real-time capability on a resource-constrained Raspberry Pi platform—something not addressed in most prior works. Additionally, unlike many previous implementations that rely on high-performance systems or require complex hardware integration, this model offers a cost-effective and scalable solution suitable for embedded vehicle environments. These advantages validate the practicality and effectiveness of the proposed system for EV security applications.

V. DISCUSSION

From the outcome, researchers have achieved all the objectives which is to achieve more than 95% accuracy of facial recognition, use ROC curve to analyze the accuracy of the face recognition, and develop the Face recognition using Raspberry Pi. When the system captures the human face, the system will undergo Principal Component Analysis to extract the significant features of the face and undergoes Support Vector Machine (SVM) to improve predictive accuracy. Before the software was implemented into Raspberry pi board, the software was evaluated with Receiver Operating Curve (ROC), the curve uses a graphical to measure the performance of a classification model. It plots the trade-off between the True Positive Rate (TRP) and the False Positive Rate (FRP) at various threshold settings. The environment must have enough lighting to make sure the camera can capture a clear facial image. The average time for the system to recognize an authorized face was about 95% and the time execution was 2.32 seconds.

The theoretical foundation of this work—specifically the use of Principal Component Analysis (PCA) for feature extraction and Support Vector Machine (SVM) for classification—is motivated by the need to implement a high-accuracy, real-time face recognition system on a resource-constrained embedded platform. By validating these algorithms through MATLAB and then deploying them on a Raspberry Pi, the study demonstrates the practical viability of transferring machine learning theory into real-world automotive security systems. This approach not only strengthens biometric security in electric vehicles but also showcases the potential for broader applications in other IoT-based systems requiring fast and reliable biometric authentication.

The validation of the proposed facial recognition system was performed using both a standard (AT&T) and custom dataset. We evaluated the model using precision metrics, including ROC curves and AUC scores. The AUC consistently reached 1.0 across 10 classes in the ROC test, indicating perfect classification performance. Furthermore, Table III provides a comparative analysis of our model against other recent approaches, highlighting superior accuracy and real-time responsiveness.

The accuracy of facial recognition using a different algorithm and database is recorded in Table III. The results show the accuracy of the proposed algorithm has the highest compared to other previous studies. The proposed algorithm proved that the accuracy of the PCA + SVM was improved compared to previous studies. This also shows that the objective number two was achieved by using SVM to analysis the system.

VI. CONCLUSION

This thesis presents the development and implementation of face detection and face recognition systems using Principal

Component Analysis and Support Vector Machine (SVM). The proposed system was divided into two parts, the first part was to analyze the reliability of the system using MATLAB software. After the system achieved 95% of accuracy above, the system was implemented in Raspberry pi board to test out with the component. The combination of both parts ensured work as a standalone device to let driver using shortest time to access their EV and increase the security of the vehicle.

This research also aimed to identify the best methods for the proposed Principal Component Analysis (PCA) and Support Vector Machine (SVM). To increase the accuracy of the system, the training photo was important, which is the size, number of training images and the resolution choose. At first the system was trained at 100 images and the accuracy was not achieved, then the training image was increased to 200 images, the accuracy improveed to 95% above. This shows that the more training images the higher the accuracy of the system.

VII. Limitation and Future Works

The limitation of the proposed methodology is that, it is time consuming in creating the face dataset. More images indicate that more individuals are required to create a customized dataset. Next, the quality of the images, the training images must have the same properties in terms of size, resolution and lighting of environment. There is also a limitation for the system which is the system can recognize a photo of an individual which means an individual can use a photo to access the system. The proposed system was aimed at improving the security of nowadays EV. The system can be installed on the door frame of the vehicle. The system ensures that only authorized person can have access to the vehicle. Besides, the proposed system can also be implemented in the home security system.

Conflicts Of Interest

The authors declare no conflict of interest.

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Authors' Contributions

The authors' contributions are as follows: "Conceptualization, Jamil Abedalrahim Jamil Alsayaydeh and Chin Wei Yi; methodology, Fatimah Abdulridha Rashid; software, Jamil Abedalrahim Jamil Alsayaydeh; validation, Fatimah Abdulridha Rashid; formal analysis, Chin Wei Yi; investigation, Jamil Abedalrahim Jamil Alsayaydeh; resources, Fatimah Abdulridha Rashid; writing—original draft preparation, Jamil Abedalrahim Jamil Alsayaydeh and Safarudin Gazali Herawan; writing—review and editing, Chin Wei Yi and Rex Bacarra; funding acquisition, Rex Bacarra and Safarudin Gazali Herawan.

Data Availability Statement

All the datasets used in this study are available from the Zenodo database (accession number: https://zenodo.org/records/15034216).

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