DESIGN AND DEVELOPMENT OF CAR IGNITION ACCESS CONTROL SYSTEM BASED ON FACE RECOGNITION TECHNIQUE

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Abstract

Automotive theft has been a persisting problem driving modern automotive designs in search of technologies to provide high security to the user. There are various methods to digitally authenticate the identity of the user, by means of non-biometric and/or biometric systems. A biometric based ID allows for the verification of “who you claim to be” based on “who you are”, in addition to checking for “what you have” (keys), or “what you know” (password). To incorporate an increased level of security, the state-of-the-art Face Recognition System (FRS) can be used which improves the accuracy with the added feature of being easy to use and maintainable for automobiles.

This paper deals with the design and development of a real time face recognition based car ignition access control system. The developed system consists of an FRS and an ignition controller unit. The FRS unit goes through the process of image data retrieval, image compression and face recognition. The captured test image passes through the face detector, where full face template matching approach has been used. The result of face detector is passed to the face compression block where an economic representation of face is implemented by applying the Principal Component Analysis (PCA) algorithm. For classifying and recognizing the test data accurately, the Euclidean-norm distance classifier is used. The Face Recognition Controller (FRC) is interfaced to the ignition controller system over CAN network. If the test face is of an authorized user, the FRC will transmit the user ID to the ignition controller and to the comfort management system allowing the user to start the car and alter the mirror position to the pre-set value.

The functionality of the integrated FRS with ignition control system is tested efficiently. The developed FRS is also tested and validated for different test cases involving varied facial expression, pose occluded face and skin color variations. The car ignition control unit of the developed system is also extended for the concept of security cum automatic comfort management system.

Keywords: Face Recognition, PCA, Euclidean-norm, Car Ignition Unit, CAN

Abbreviations
ADC Analog to Digital Converter
CAN Control Area Network
CCD Charge Coupled Device
CIA Car Ignition Access
FRC Face Recognition Controller
FRS Face Recognition System
GUI Graphical User Interface
HSV Hue, Saturation, Value
LCD Liquid Crystal Display
MATLAB Matrix Laboratory
PCA Principal Component Analysis
RGB Red, Green, Blue
UART Universal Asynchronous Receiver/Transmitter
USB Universal Serial Bus
YCbCr Luminance, Chrome blue, Chrome red

1. INTRODUCTION

Automotives thefts are increasing alarmingly around the world. To give protection to drivers, automotives vehicle manufacturers are making their products more secure by dumping technologies into automobiles. The key and the basic process of security system involve how it identifies the validity of the user. Biometric and non-biometric are two ways of identifying a person. Non-biometric identification system uses a serial number such as personal ID and password to identify a person; however, non-biometric ID could be forged or taken/stolen by others, which restricts the verification or validity of the ID holder. Biometric identification based security systems are considered to be the most secure especially due to their ability to identify people with minimal ambiguity. A biometric based ID allows for the verification of “who you claim to be” based on “who you are”, in addition to checking for “what you have” (keys), or “what you know” (password) [1]. This increases the security of the overall identification system and improves the accuracy and speed of automobile owner identification. The Fig. 1 shows the different security levels of automotive anti-theft systems.

Fig. 1 Classification of security systems [1]

This paper deals with the advanced security access system aimed to demonstrate the facial recognition techniques that could antiquate, substitute, or otherwise,
supplement conventional key vehicle ignition systems. The process of existing biometric recognition system using iris, fingerprint, voice and palm geometry to identify a person is complex, also demanding the cooperation of users [2]. On the contrary, in FRS, a camera from a distance captures a user’s face, henceforth, highlighting the covert capability of the FRS (i.e., the subject does not necessarily know he has been observed). For this reason, FR can provide better security compared to other biometric security systems, along with its added feature of being easy to use.

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Fig. 2 Basic block diagram constituting the FR and CIA system

The Fig. 2 shows the basic block diagram of the face recognition based Car Ignition Access (CIA) control system. For the functioning of the FRS, the system requires both training data and test data. The training data consists of few user face images against which the input test face image is tested and the corresponding match is obtained. The user information obtained from the FRS will be passed to car ignition control and comfort management system. Necessary interfaces to communicate with the car ignition unit are provided in the car ignition controller. According to the user ID, the ignition controller controls the car ignition and also sets the side mirror position to the predefined user settings.

Fig. 3 System concept model

Acquisition of image is carried through CMOS camera and the acquired digital images are fed to the face detection block. During face detection process, background disturbances pose a challenge for accurate face recognition. To overcome this challenge a composite color mapping skin color segmentation is introduced which will enhance the performance of the face detection block. The focused face image will then be subjected to face compression block for economic representation of face by retaining most of the principal components required by means of applying the Principal Component Analysis (PCA) algorithm. PCA can map the large dimensionality of the data space to the smaller intrinsic dimensionality of feature space, which is needed to describe the data economically. The face classifier processes these compressed face images and recognize the test data from the training data. For classifying and recognizing the test data accurately, the Euclidean-norm distance classifier is used.

The realistic visual models (concept model) of the face recognition based car security system are shown in Fig. 3. It shows the different views of the model where the hidden camera is placed in the steering of the car along with LCD message display screen and keypad for user interactions.

The various terminologies involved for face recognition process include; face detection, face compression and face recognition

1.1 Face Detection

In face detection the presence of face in the given image is determined by means of skin color composition as claimed by Singh et. al. [2]. The experiment carried out shows that HSV colour space based skin color extraction can provide better performance than other color spaces [3]. YCbCr, HSV color spaces are generally used to filter the face image. T. Acharya and A. Ray [4], discuss about different color spaces and its critical thresholds used for human skin detection.

Though RGB, YCbCr, HSV, HSI and TSL mentioned in reviewed literature are commonly used for skin color detection, their performance is found to be less optimal for applications where skin color variations are concerned. Hence a combination of HSV and YCbCr colour space provide accurate results for skin color detection. The identified thresholds from the reviewed literature for skin color segmentation were found to have constraints for Asian skin color. In order to overcome these constraints, an optimum choice of thresholds composed from combined color spaces are being used whose results were also found encouraging for real-time applications.

1.2 Face Representation

Eigenface is one of the most thoroughly investigated approaches in face recognition. References [5, 6, 7 and 8] use PCA algorithm to efficiently represent pictures of faces. The weights describing each face are obtained by projecting the face image onto the eigenface. As the images include a large quantity of background area, the above results are influenced by background. The above references explained the robust performance of the system under different lighting conditions by significant correlation between images with changes in illumination. However [9], showed that the correlation between images of the whole faces is not efficient for satisfactory recognition performance. Hence, in this paper the face focus algorithm is considered which restrains the content of the image within the face, eliminating the background.

1.3 Face Classification

PCA algorithm assisted with Euclidean-Norm classifier produce accurate results provided the number of images used in training phase is less and distinctive.

1.4 Ignition Control Unit

Now in modern automotives ignition and fuel supply are controlled by electronic control systems. So it is easy to control ignition and fuel supply. Hence in this paper Ignition plus Fuel supply shutoff control
based car anti-theft systems is used to provide better security.

2. DESIGN AND DEVELOPMENT OF FR BASED CIA CONTROL SYSTEM

2.1 CIA Control System Specifications

<table>
<thead>
<tr>
<th>Platform</th>
<th>Blackfin DSP Processor BF533</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>VisualDSP++, MATLAB, LabVIEW</td>
</tr>
<tr>
<td>Camera</td>
<td>CCD Camera</td>
</tr>
<tr>
<td>Interfaces</td>
<td>PPI interface between Camera and BF533</td>
</tr>
<tr>
<td></td>
<td>CAN interface b/w BF533 and LPC2129</td>
</tr>
<tr>
<td></td>
<td>UART interface b/w BF533 and PC</td>
</tr>
<tr>
<td>Image Classifier</td>
<td>Euclidean-norm distance Classifier</td>
</tr>
<tr>
<td>End User Interface</td>
<td>LCD Display and Keypad</td>
</tr>
<tr>
<td>Car Access controller</td>
<td>ARM 7 TDMI</td>
</tr>
<tr>
<td>Face Identification Algorithm</td>
<td>A Combined Color Space Skin Detection</td>
</tr>
<tr>
<td>User Comfort Management</td>
<td>Side mirror controller</td>
</tr>
<tr>
<td>Car Ignition Unit Interface</td>
<td>Ignition relay, Ignition switch and Fuel shut off valve</td>
</tr>
<tr>
<td>Main Face Recognition Controller</td>
<td>ADSP BF533</td>
</tr>
<tr>
<td>Face Compression and Recognition Algorithm</td>
<td>PCA</td>
</tr>
</tbody>
</table>

Fig. 4 Block diagram of CIA control system

The block diagram of CIA control system based on FR Technique is shown in the Fig. 4. The system mainly has two sections, FRS and Ignition control system. The DSP image processing unit is headed by a DSP processor (ADSP BF533). It is having a PPI interface with CMOS camera, USB interface with the host system (PC) and UART interface to the CAN controller module. The ignition control system uses LPC2129 board (ARM 7 TDMI); having sub modules like keypad, fuel shut off valve (DC motor), LCD monitor and side mirror control module (Stepper motor, Potentiometer and its drivers).

2.2 Face Recognition Algorithm

The Fig. 5 shows the flowchart of FRS incorporating face focus algorithm, PCA and image classifier. First process is training; the training images are converted to a single 2D variable and given to mean value corresponding to each row. Then the mean from training images is subtracted to obtain mean centered image. The covariance matrix from the mean separated training image data is calculated[14].

\[
\text{Covariance} = \frac{1}{(N-1)} \times \text{data} \times \text{data}' 
\]  

\text{(1)}
The eigenvectors and eigen-values of the covariance matrix are found. The diagonal elements of the eigenvector matrix are extracted and the variances in decreasing order. The original data is set projected to find the eigenfaces. Map each training image to reduced dimensional space using the eigenfaces. The test image is captured and stored in Blackfin memory as the input test data. The face focus algorithm is run on the test image to eliminate the background image. The mean is subtracted from face focused image and the test image is mapped to the weight space. The test weight space data is compared with the training space and the result is declared. During the first run, the projected trained face space image is stored in Blackfin memory. On the next run, the saved training space alone is used for face recognition of new input test data. This process resulted in reduction of execution time.

2.3 Face Detector

Different color spaces listed in the literature review has been tried to detect face from the image, but the performance in real-time environment was not satisfactory. Hence in this paper we propose a composite color space to effectively extract skin color from an image with less sensitivity to luminance. The composite color space maps the RGB image to an HSCbCr (Hue, Saturation, Chrome blue, Chrome red) color space. The equations for calculating Cb and Cr from RGB color space are shown in Eq. 2.

\[
\begin{align*}
Cb &= 128 - 0.168736R - 0.331264G + 0.5B \\
Cr &= 128 + 0.5R - 0.418688G - 0.081312B \\
R, G, B, Y, Cb, Cr &\in \{0,1,\ldots,255\}
\end{align*}
\]  

(2a)

The flow chart of the face detector algorithm is illustrated in Fig. 6.

2.4 PCA Dimensionality Reduction

The aim of PCA is to reduce the dimension of the face space. The maximum number of principal components is the number of variable in the original space. However, in order to reduce the dimension, some principal components should be omitted [6].

The reconstruction of a face \(x_i\), by the components \(y_i\), is given by the following formula:

\[
x_i = P * y_i
\]

(5)

If \(p_i\) are the column vectors of \(P\), i.e., the basis vectors, then, the reconstruction of a face, using only some of the components \(y_{ij}\) is:

\[
\overline{x_j} = \sum_{j=1}^{M} y_{ij} * p_j + \sum_{j=M+1}^{K} y_{ij} * p_j
\]

(6)
\[ e = x_i - \bar{x}_i = \sum_{j=M+1}^{K} (y_{ij} - a_{ij}) \cdot p_j \] (8)

The error vector is a random vector and its effectiveness is calculated by its mean square value:

\[ <e^2> = (e^T \cdot e) \]

\[ = m \left( \sum_{j=M+1}^{K} \sum_{j=M+1}^{K} (y_{ij} - a_{ij}) \cdot (y_{ij} - a_{ij}) \cdot p_i^T \cdot p_i \right) \]

\[ = \sum_{i=M+1}^{K} m \left[ (y_{ij} - a_{ij})^2 \right] \] (9)

Omitted values of \( y_i \) have to be replaced by their mean value in order to minimise the reconstruction error. The error vector becomes:

\[ <e^2> = \sum_{i=M+1}^{K} m \left[ (y_i - \mu(y_i))^2 \right] = \text{sum of the variance of the omitted components} \] (10)

If the eigenvalues are classified in decreasing order, the last eigenvalues (and their eigenvectors) may be dropped. This represents the dimensionality reduction of PCA. In effect this means that some principal components can be dropped because they explain only a small amount of the data, whereas the largest amount of information is contained in the other principal components. The amount of information that the \( i \)th principal component carries is given by its eigenvalues, \( \lambda_i \). Usually the principal components (eigenvectors) are sorted in the decreasing order of their eigenvalues and the last ones are dropped. This fact is particularly important when augmented by the knowledge that for faces the decreasing of the eigenvalues is exponential.

2.5 Image Classifier

The test image vector and training image vectors will be given to the image classifier, to measure face distance using the following formulas,

**Euclidean Norm distance**

\[ \text{Euclidean distance} = \sqrt{||P_1 - Q_1|| + ||P_2 - Q_2|| + \ldots + ||P_n - Q_n||} \]

\[ = \sqrt{\sum_{i=1}^{n} ||P_i - Q_i||} \] (11)

Same way test image will be compared to all the training vector. Then is computed nearest neighbor face from the training faces. If the distance is more than a threshold the test image will be declared as unknown face.

2.6 Ignition Controller Design

Ignition Controller first performs a primary security (password) check; if password is correct the user will get limited access to the system. The user information data received from FRS through CAN is validated for user identity. In case of a valid user ID, ignition will be turned on and fuel shut off valve will be released. If the user validation fails for more than five times, the system activates a buzzer alarm. It can only be released by a successful user login. In addition if the user login is successful then the side mirror menu will be displayed and the user can set or reset the position of the mirror.

2.7 Schematic Circuit Diagram of CIA Control System

The schematic circuit diagram of the FR based CIA control system is shown in Fig.7.
communicator. The user ID information will be transferred to CAN communicator through the UART using ADM3202 RS-232 line driver, this will be retransmitted to the ignition controller through the CAN protocol. A LCD is interfaced to the board to display alert messages. The LCD is connected to the PORT 2. From PORT 1 a line is connected to the buzzer to produce emergency alarm. The ignition switch (relay) is connected to PORT 1 of LPC2129 through a buffer IC. The L293D driver IC is used to interface the DC motor with the controller. The potentiometer is connected to the first channel of ADC input (ADC1). It effectively makes the side mirror control system a closed loop system. The side mirror is positioned by the use of stepper motor that is driven by a stepper motor driver IC ULN2003 and it can provide by-directional rotating capability.

2.8 MATLAB and LabVIEW SIMULATION

The MATLAB simulations of the face detector and face recognition algorithms are shown in Fig. 8. The face detector is tested with different color spaces, from the color space defined and is capable of accurate face detection and filtering. Current face recognition algorithm is tested and validated for various test cases such as objects partially covering face, different poses, and light intensity variations.

![Fig. 8 MATLAB simulation of face detector and face recognition algorithm](image)

The MATLAB validation of the current face detection and face recognition algorithm were successful and the complete integrated real-time system is simulated using LabVIEW, where LabVIEW is used for creating GUI and a plug-in for MATLAB M files. The Fig. 9 shows the real time LabVIEW simulation system front panel.

3. RESULTS AND DISCUSSIONS

The validation and verification of the face recognition algorithms, integration of FRS with the ignition controller and complete CIA control system were successful. Test cases are successfully executed in both simulation and implementation phases. DB7-FERSTI-Asian-Indian-Female face image database is used for this purpose [15].

The Fig. 10 shows the FRS test case execution on the ADSP BF533 and shows that the designed FRS is successful in the case of objects partially covering face, dynamic background images and with all normal expressions. The system fails in the presence of high light intensity images, shadow images and extreme expression faces. Due to memory constraints only two training images per user were used for implementation on the Blackfin processor. If the memory constrain issue is resolved and if the processor can store more number of training images, then the recognition rate of the system will increase.

The experimental setup of the CIA control system is shown in Fig. 11. In this setup, the relay and LED are used to mimic the ignition switch and the fuel shut off valve is represented by DC motor. The side mirror adjustment mechanism is replaced by stepper motor, gears and potentiometer.
3.1 FRS Performance Characteristics

The performance characteristic of the FRS, in both simulation and implementation phases is detailed in Table 1 based on operation timings. The face detection and face recognition algorithm implementation on DSP BF533 executes almost same speed as MATLAB simulation. But to load the training image the BF533 takes huge time. So the total execution time on processor is more as compared to the simulation. Once the images are loaded to the Blackfin memory the face recognition algorithm executes at a faster rate.

The full camera integrated system is impractical due to the limited array handling capacity of Blackfin BF533 and memory corruption. The performance of the non-real time system’s (feed image from VDSP++ emulator) implementation of the car anti-theft system is successful.

3.2 Ignition Controller Performance

The CIA control system has three end systems; i.e., ignition control switch, fuel shut off valve and side mirror control system. This paper demonstrates these systems using some experimental components, whose characteristics are similar to the real system.

- **Ignition Switch** is implemented using a relay and LED. In real car it will act as a hidden switch between ignition coil and battery. It’s successfully activated by user login.
- **Fuel Shut off Valve** is implemented using DC motor, the performance is reliable. This blocks fuel flow until a FRS identify a valid user.
- **Side Mirror Position Control System**: The side mirror adjustment mechanism is replaced by stepper motor, gears and potentiometer in experimental setup. This setup effectively positioned the side mirror motor.

4. CONCLUSIONS

In this paper, a special case of face recognition algorithm (Face filter + PCA) is used. The developed FRS has achieved higher accuracy than the typical PCA. The system is capable of recognizing faces and overcome following challenges,

- Objects partially covering face (e.g.: Sun Glasses, Long Hair)
- Low resolution images
- Facial expressions
- Dynamic background
- Skin color variations

Although a number of efforts has been made on pose-invariant face recognition, the performance of current face recognition system can still be improved. Sensitivity to extreme poses and different lighting conditions is still a challenging problem.

The experimental result of the developed system is also extended for the concept of security cum automatic comfort management system.
5. REFERENCES


