Face recognition algorithms for embedded entrance guard system

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Received 1 March 2014, www.cmnt.lv

Abstract

Biometric identification technology is used to identify individuals based on their unique physiologica1 characteristics under sampling and measurement. The hardware platform of our entrance guard system is based on SAMSUNG S3C6410 embedded development board with ARM11 processor, and we adopt ordinary camera as facial image capture device, 7-inch touch-screen LCD display as an input, electronic door locks as executing components by the onboard port control. The software platform is based on Linux operating system to design and optimize face recognition algorithm, which is combined with local binary pattern (LBP) algorithm, principal component analysis (PCA) algorithm, and ridge regression algorithm. Also, the face recognition system is divided into two parts, namely, a face database training part and a face recognition part. Precisely, the face database training part acquires face information through the processes of face detection, feature extraction and stores the face information to serve as the detection basis of the face recognition part; then the face recognition part is connected with the entrance guard system and sends out an instruction for executing related action to the entrance guard system according to the face recognition result. Specially, the embedded face recognition entrance guard system is contactless and easy to collect the facial database, less in power consumption, low in cost, and has easy installation and stable performance.

Keywords: face recognition, local binary patterns, principal components analysis, embedded system

1 Introduction

The face recognition process is to identify or verify one or more persons in the scene using a stored database of faces for some given still or video images of a scene. Compared to fingerprint recognition, retina recognition, iris recognition, gene recognition, handwriting recognition, voiceprint recognition, the advantages of face recognition are hidden operation and contactless collection, and it accords with the human recognizing habits. By further analyzing the facial expression and pose, one can get some information that is not available on other recognition systems.

Biometric identification technology is used to identify individuals based on their unique physiologica1 characteristics under sampling and measurement. Since biometric characteristics are not easy to be stolen as the certificate holdings, and be forgotten or cracked as passwords, biometric identification has been extensively applied in public security for these unique benefits of biometric characteristics. And recently, face recognition technologies have been extensively studied and applied in China and abroad. In particular, the face recognition system based products lead to small volume and low power, meanwhile the face recognition technologies lead to contactless mode, thus one need not worry the situation whether they would be willing to touch the collection equipment because of public health. On the other hand, current application of face recognition technology has three main respects, i.e., criminal detection, identification inspection, and access control. For example, at the entrance of the building, district, factories, house and the parking lot, the frequent in-and-out causes high management difficulty in verifying procedure by security personnel. However, face recognition technology can be used in entrance guard system to realize the entrance controlling based on face recognition, supplemented by other recognition [1-3].

Traditional face recognition entrance guard system is based on the PC or server, which has some defects such as high cost and large size. With the rapid development of embedded technology, the face recognition for embedded application system is becoming increasingly intelligent, miniaturized and portable.

2 Overall design

Face recognition system consists of five modules: facial image acquisition module, image pre-processing module, face detection and localization module, facial feature extraction module, and face classification module. The overall design of entrance guard system is (Figure 1):

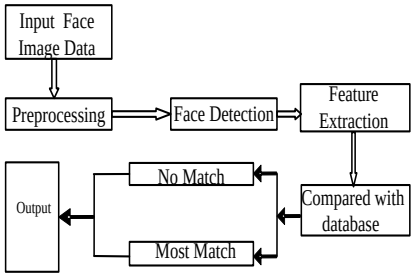

FIGURE 1 The overall design of Entrance Guard System

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The face recognition for embedded entrance guard system is the aggregation of computer hardware and software, including the face recognition subsystem and entrance guard system, wherein the main function of the face recognition subsystem is to collect face information and execute and output the results. Additionally, main related hardware and software include camera, computer hardware system, Linux operating system, Open Source Computer Vision Library (Open CV), and some self-designed application software. Under such entrance guard system, one can realize the following modules:

1) Face Detection Module: in the system initialization phase, the computer will detect the image captured from the camera whether or not a human face exists.
2) Face Recognition Module: in the face detection phase, after collecting the face information, do the face localization, feature extraction and comparison with database, and output the results.
3) Face Register Module: the registration function is enabled to make a new record input after successfully recognizing a person's face. To improve the safety, only the users whose face information is collected in the database can be authorized to make a register.
4) Face Training Module: the training function is to train the face in the database. In fact, one extracts the face feature and then classifies and labels for saving. The purpose of the face training database is to compare with the extracted feature by face recognition process and then output the results.
5) Access Control Module: the entrance guard system is one part of the hardware platform, whose main function is to receive signals from face recognition software system, then it will drives the switch of electronic lock.

3 Hardware design

The hardware platform is based on the Samsung S3C6410 board with ARM11 processor,600MHz CPU frequency, 256MB RAM memory capacity, 2GB NAND Flash capacity, and we adopt ordinary USB camera as facial image capture device, 7-inch LCD screen as display device, touch screen as an input, electronic door locks as executing components by the onboard port control [4].

The drive of face recognition for entrance guard system is used to drive the electronic pin, whose function is to control the switch of the door. When the input is connected to the S3C6410 board, it will detect and successfully recognize the facial information, then the development board outputs high level signals, turns on the thyristor and suctions the electronic pin. Herein the electronic pin is a coil with one diode in each end in order to avoid the breakdown of thyristor by instant high pressure. The manual control switch is not only used to suction the electronic pin, but also reset it by making the signals of the anode and cathode of thyristor in the low level.

The layout of embedded entrance guard system is shown (see, Figure 2), in which the electronic pin is situated above the door.

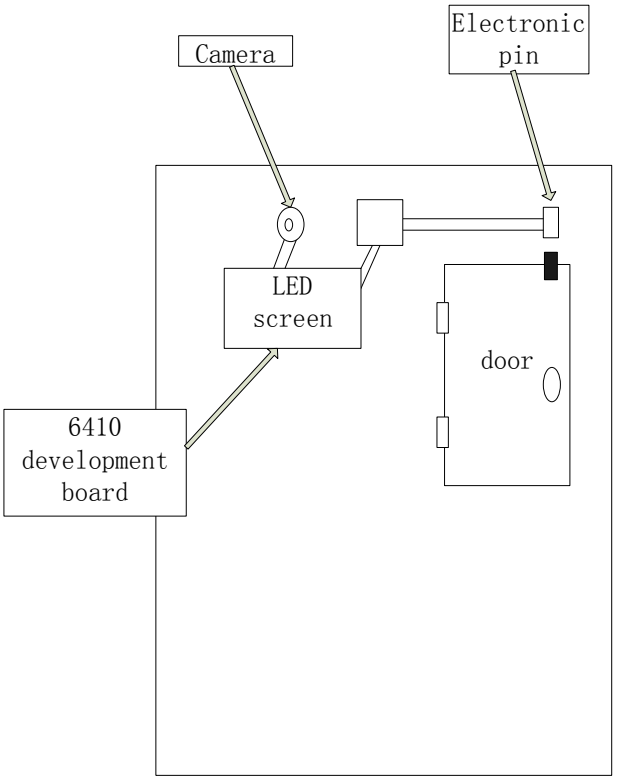

FIGURE 2 The layout of the embedded entrance guard

The door will open when the electronic pin suctions, while the door will close when the electronic pin resets.

4 Algorithm design

The face recognition system is composed of facial image acquisition, facial image pre-processing, face detection and localization, facial feature extraction, and face classification. The face recognition algorithm is combined with local binary pattern (LBP) algorithm, principal component analysis (PCA) algorithm, and ridge regression algorithm. The flow chart of face recognition system is shown (Fig. 3):

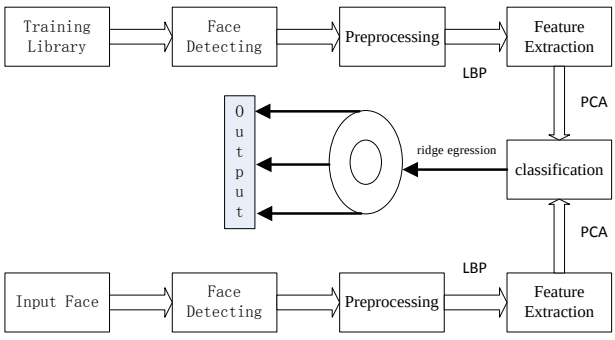

FIGURE 3 The flow chart of face recognition system

Firstly, the LBP algorithm can describe some tiny features (light spots, dark spots, stable area and the edge of various directions), and reveals the distribution of these features, which improves the performance of facial image recognition. Secondly, the PCA algorithm can map the high dimensional data to low dimensional to reduce the amount of calculation for one side and extract the key data

to minimal interference for the other. Finally, the ridge regression algorithm is applied to classify the mapping data by PCA algorithm in order to get the mapping vector of face training dataset and then save the training results.

4.1 LBP ALGORITHM

The basic idea of LBP algorithm is to label the pixels of an image by thresholding the neighborhood of each pixel and consider the result as a binary number [5-7]. For the face recognition system, we apply the LBP algorithm to each divided block of preprocessing image and analyze the LBP histogram, and then we obtain the feature histogram [4-6]. The so-called uniform patterns can be used to reduce the length of the feature vector and implement a simple rotation-invariant descriptor. A local binary pattern is called uniform if the binary pattern contains at most two bitwise transitions from 0 to 1 or vice versa when the bit pattern is traversed circularly. For example, the patterns $U(00000000) = 1$, $U(11111111) = 2$ and $U(11001111) = 2$ are uniform whereas the patterns $U(11001001) = 4$ and $U(010100010) = 6$ are not.

The uniform patterns LBP algorithm is defined by

$$\mathrm{LBP}_{P,R}^{riu} = \begin{cases} \sum_{i=0}^{p-1} s(g_i - g_c), U\left(LBP_{P,R}\right) \le 2, \\ P+1, other, \end{cases} \quad (1)$$

where:

$$\mathrm{U}\left(LBP_{P,\ R}\right) = |\mathrm{s}(g_{P-1} - g_c) - s(g_0 - g_c)| + \sum_{i=1}^{P-1} |s(g_i - g_c) - s(g_{i-1} - g_c)|. \quad (2)$$

From Equation (1), there are $P + 1$ uniform patterns when using P pixel neighborhoods. These uniform patterns are labelled as 0, 1, …, P, while the non-uniform pattern is labelled as $P + 1$. According to LBP operator feature, the face image is divided into 4×4 blocks. In this paper, the height and width are set at 96 pixels, and the LBP codes in an image are collected into a histogram.

4.2 PCA ALGORITHM

The eigenface approach began with a search for a low-dimensional representation of face images. In 1991 M. Turk and A. Pentland presented the eigenface method of face recognition [8-10].

Denote the facial data by:

$$X^i = \left(X_1^i, X_2^i, \cdots, X_d^i\right), i = 1,2,\cdots,k., \quad (3)$$

Then the covariance matrix is

$$\mathrm{S} = \frac{1}{k-1}\sum_{i=1}^{k}(X_i - \bar{X})(X_i - \bar{X})^T. \quad (4)$$

Next we adopt a computationally feasible method to determine the eigenvalues λ_i and eigenvectorsv_i of S, where i = 1, 2, …, d. Then we sort λ_i from largest to smallest and choose the first n ones, where $n < d$ to build a transfer matrix $\mathrm{A} = [v_1, v_2, \cdots, v_n]$. For the X data, $Z^{'} = A(X - \bar{X})$ its eigenvalues yields.

In our test, the face image is considered as a high dimensional vector, so that a typical image of size 100 by 100 becomes a vector of dimension 10,100, or, equivalently, a point in 10,100-dimensional space. We then adopt LBP algorithm for texture analysis, and output the histogram equalization with P=8, which implies that there may be $10(P + 2)$ uniform patterns. Also, the face image is divided into 4×4 blocks, and then this high dimensional vector reduces to a vector of dimension 160. Next, through the face training database, and save the LBP outcome as declared variable 'CvMat*', and face feature before reducing dimension as matrix 'm_pTrainingFaceX' with 160 rows and N columns, where N is the total number of images of face training database. Herein we collect 10 images for each person and save them to separate directory named by ID.

4.3 RIDGE REGRESSION ALGORITHM

The last processing flow of face training is to classify the face data by ridge regression algorithm [11,12]. We first introduce the main idea of this regularization method. Motivated by the fact that the m vertices of a regular simplex is the most balanced and symmetric separate points $v_i(i = 1,2,\cdots,m)$ in the m-dimensional space. We choose these vertices as the targets for m distinct face images, and apply ridge regression to train a linear model W, which maps the training face images $I_i(i = 1,2,\cdots,n)$ into the m-dimensional subspace such that the distance between each mapping result and the vertex is minimum. Herein each training sample$I$and each vertexvcorrespond to the independent variable x and dependent y variable of multivariate linear model, respectively.

Assume that there are n training samples for face classification $\{(x_i,\ y_i)|i = 1,2,\cdots,n\}$, where x_i denotes p-dimensional vector for face images of high dimension, and y_i denotes r-dimensional vector for face images of low dimension. As a result, the task of learning classifier in multivariable ridge regression algorithm is to find a matrix $\mathrm{W} \epsilon R^{P\times R}$ that can model the linear dependency between the image x_i and the label y_i to minimize the objective function:

$$J(W) = \sum_{i=1}^{n}\|W^T x_i - y_i\|^2 + \lambda\|W\|^2 = \mathrm{tr}(YY^T + WTXXTW - 2WTXYT + \lambda trWTW, \quad (5)$$

where $\mathrm{X} = [x_1, x_2, \cdots, x_n]$, $\mathrm{Y} = [y_1, y_2, \cdots, y_n]$ and tr stands for the trace of matrix.

Taking derivative of Equation (5) with respect to the W and equalling it to zero, we have:

$$\mathrm{W} = (XX^T + \lambda I)^{-1}XY^T. \quad (6)$$

Let x be a new image, the projecting value in the subspace is $W^T\boldsymbol{x}$, the class of minimum distance of x.

Suppose there are m face images to be recognized, we can construct m points in R^{m-1}such that these m points keep isometric under translation and rotation. In summary, the procedure of ridge regression algorithm for face recognition can be formally stated as follows:

1) Compute the mapping matrix W from (6).
2) Compute the map $y = W^T \boldsymbol{x}$ for a new face *x*.
3) Compute the distance $\|y - T_i\|$ between y and each label $T_i (i - 1,2,\cdots,m)$, and denote $\arg\min_i \|y - T_i\|$ as the class of *x*. The input is the data after reducing dimension, which is the matrix 'm_pTrainingDataX' with 70 rows and *N* columns, where *N* is the total number of images of face training database.

We firstly label the data after reducing dimension and construct the label function, and then compute the classifier by ridge regression algorithm. Here the input parameter of the function 'trainW()' is the directory of face training database. Also this function can save the key data such that it avoids the training procedure of face recognition.

The key data and saved variables and their description are listed in Table 1:

TABLE 1 The Variables and their file name and description

Variable	File Name	Description
m_pTrainingResW	TrainingRes.txt	TRAINING RESULTS
m_pRegSimVerT	T.txt	MATRIX MARK VECTOR ALL FACE CATEGORIES
m_pMeanOfFaceX	Mean.txt	AVERAGE VECTOR FOR PCA BEFORE REDUCTION DIMENSION
m_pEigVecs	EigenVectors.txt	FEATURE MATRIX PCA REDUCING DIMENSION
m_vecPersonName	PersonName.txt	THE ID OF FACE CATEGORIES
m_ifaceHeight **m_ifaceWidth**	ImageSize.txt	FACE IMAGE SIZE(HEIGHT AND WIDTH）

ID recognition can be carried out independently with face recognition, but the recognition must adopt the face training results, therefore one need to check whether the variable is null before face recognition. If yes, one must import the data according to variables and file name from Table 1.

Next combination with the LBP pre-processing, PCA reduction dimension and ridge regression mapping results in a map vector, and compare this vector with the training result in order to find the ID with minimum distance. Finally these operations are wrapped to drive the application program.

5 Application software design

Our software platform is based on Linux kernel (2.6.29), and we adopt Qt 4.73 as the user interface, Open CV 1.0 as face database. The framework of our application software is shown (Figure 4):

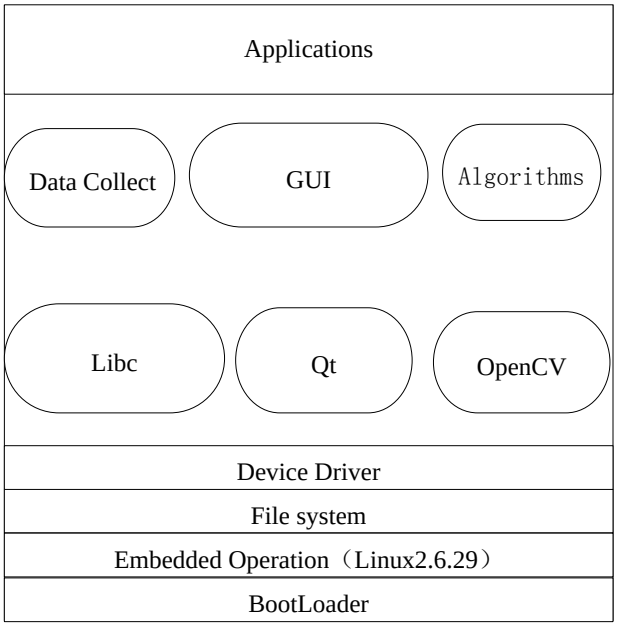

FIGURE 4 The framework of application

The applications are composed of Bootloader, Linux operation system (2.6.29 kernel), Qt libraries, Open CV library, embedded file system, driver program and GUI. Herein Open CV is a popular computer vision library started by Intel in 1999. The cross-platform library sets its focus on real-time image processing and includes patent-free implementations of the latest computer vision algorithms. Qt is a cross-platform application framework that is widely used for developing application software with a graphical user interface (GUI) (in which cases Qt is classified as a widget toolkit), and also used for developing non-GUI programs such as command-line tools and consoles for servers. Qt is fully object-oriented, easily extensible, and allows true component programming [13, 14].

In the Samsung S3C6140 development board, we compile the vivi bootloader, and configure Busybox with dev support. Licb library is the standard C libraries on Linux, and the compiler is installed in the user directory, and then it is copied into embedded root directory. Thus we complete the basic embedded root file system and make it as mapping commands by 'mkyaffsimage' program, and then to write vivi to flash root partition.

Additionally, the source codes need to be compiled before transplanting the Qt library in order to accommodate the Samsung S3C6410 platform. Since it takes the touch screen as input, one must import 'tslib' library to ensure that the touch screen driver can be used normally by GUI interface designed by Qt library.

Next we compile the Open CV library and V4L2 camera driver to get the video frames and map them to user memory, and then convert the frames encoded in YUV format to RGB format to generate the picture on a computer screen. According to the YUV/RGB conversion formula, we write the conversion function. So the RGB frames can display in Qt, and thus we can use some image processing function in Qt to process or save.

This system can achieve the following objectives: the recognition rate reaches more than ninety-eight percent; users can import a new member by the user registration function; the recognition speed can be five second or less; it provides a good interactive interface; it minimizes the energy consumption as much as possible; the whole system has high integration.

6 Face recognition system testing

The implementation of detection of face recognition system is divided into two parts, namely, a face training part and a face recognition part, and the latter use the parameters and outcome from the former, while both use the same face detection technology.

The testing program is to test the recognition rate and the accuracy of face recognition algorithm, where face database includes the internet open access resources and the face images appended by user. The design principle of our face database is to extract 16 people from in the face database from internet open access resources, each with 20 images, where we use 10 images as face training database and others for testing. On the other hand, we append two people (one with 20 images and another with 23 images) into the face database, and extract each with 10 images as face training database and others for testing.

Now we introduce the procedure of face recognition testing. Firstly, we activate the camera to capture face and recognize it. If that face to be recognized is not saved in the database then the algorithm program will display 'nobody'. If the face to be recognized is registered in the system, then the training function will build a folder with the name 'cj', and save 10 shots with different facial expression. Therefore, the face recognition system will activate the camera to capture image and compare it with the backend database, then it will recognize the information of 'cj', and save 10 shots with different facial expression, shown in Figure 5.

Therefore, the face recognition system will activate the camera to capture image and compare it with the backend database, then it will recognize the information of 'cj', so it will activate the embedded application system to open the door for this authorized person.

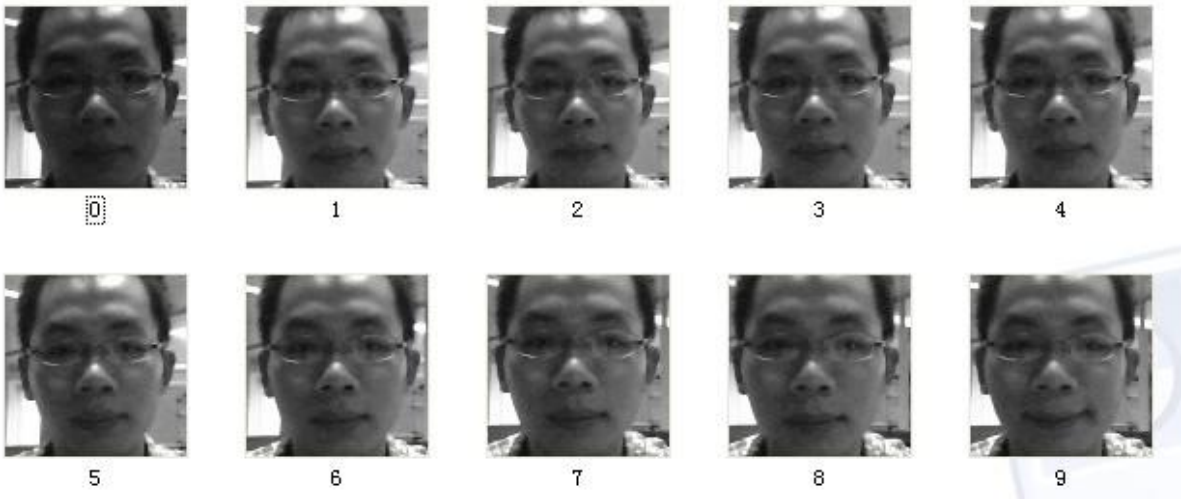

FIGURE 5 Face data

7 Conclusions

Face recognition technology is a hi-tech security way, which has superiority beyond comparing with other recognition approaches. Since it has a high accuracy rate, fast speed and difficultly counterfeited, the face recognition system is very suit for places where high safety is called for. Compared to some unique feature such as DNA, fingerprint, or iris, the face will change as one grows old, and collected images are disturbed by illumination, pose, expression, and makeup. But there exist some similar faces like the identical twins, so there may be uncertainty about face recognition. To improve the information security, one can adopt various recognition approaches to control the access.

For the current urgent need for security, we design an entrance guard system by face recognition and combine the ID registration technology to pre-register personnel in and out. Furthermore, we should update the samples in face database [15]. Finally, our system can be applied to finance, securities, social security, police, entry/exit port and other security authentication industry and sector.

Acknowledgments

This work was supported by Guangdong Provincial Scientific and Technical Project of China under Grant No. 2012 B010900089.

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