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An intelligent human behavior based automatic accessing control system

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Abstract: In this paper, an innovative intelligent controlling system for automatic door accessing is proposed to improve the drawback of frequent false actions among the existing control systems, while increasing the added values for extra security applications. Through pattern recognition techniques, the proposed system can precisely identify those people with intention of entering and/or leaving the door, and then control opening and closing of this door as a response. The experimental results indicate that our system has the advantages such as high precision, high reliability, and controllability in response to demands. In addition, the product prototype also has the economic benefits of low costs, high added-value, etc. Thus, it is a highly competitive new product.

Keywords: automatic door controlling, behavior analysis, human detection, pattern recognition

1 INTRODUCTION

Automatic door control is convenient and is widely used in many public places such as shores, businesses, transportation stations, airports, and wholesale department stores to eliminate the need of manually opening and closing the doors. However, there exists severe drawback in the existing approaches, ex: they are unable to determine the type and the intention of the detected object. In other words, a puppy or a bicycle passing by will trigger an action to open the door. In addition, even with the help of other technologies they may verify that the object is a person, they are still unable to indentify the intention of the person. For instance, a pedestrian or a person stays close to the door chatting might still trigger the door opening/closing. Frequent false actions not only wastes control and air conditioning energy, but also reduces equipment life time. This calls for the needs of an automatic door control system based on image recognition and intention analysis.

In the proposed method, the action of the door is based on the confirmation that the object is a human body, and movement trajectory indicates his/her intention to access the door. In our approach, an anti-pinch measure has been added to eliminate the false actions among existing systems. We detect the existence of human face other than the human geometric shaped (head, torso) scheme since it is well developed with reasonable detection rate and has the closest resemblance to real human characteristics. In addition, the images can also be saved for latter analysis for the applications such as crime investigation and prevention.

This paper is organized as follows: Section 2 describes the system design concept and related theoretical basis, while the corresponding hardware implementation architecture is described in section 3. Section 4 states the results and the analysis of various field tests of the system prototype, followed by discussions. Finally, the conclusion and future work are made in the last part.

2 THEORETICAL BASIS

2.1 Human face detection

The related researches on human face detection in the past ten years can be classifies into two types: the detection method based on skin color characteristics [1] and the detection method based on the training of human face database [2-4]. The former considers the blocks with the known skin color characteristics in the images as candidate blocks, and then the existence of isosceles triangles formed by eyes and mouth within the blocks can be used to confirm human faces. In the latter method, neural networks [2] or Adaboost [3-4] training methods are used to find human facial features and detect human faces in the established facial image database. The proposed system will use the Adaboost human face detection method to determine the existence of human object.

2.2 Analysis of the object moving trajectory

To determine whether the human object in the monitored areas has the intention to enter the door, the cumulative density function (*CDF*) obtained from tracking the trajectory of the human face movement is used to determine if the person has the intention to enter the door. Thus, this section will be divided into two parts: the tracking of human faces and the estimation of probability distribution of movement trajectory. In the first part, the tracking of human face is realized by comparing if the overlapping area of human face between time t and $t-1$ is smaller than the threshold value. In the second part, the human face moving trajectory of the person with the intention of entering will be estimated to figure probability distribution of x and y axis. Then this probability distribution will be used to establish the probability matrices of the monitored areas to estimate the probability values corresponding to different positions. Finally, this probability value will be used to calculate the cumulative density function corresponding to the movement of each human face to determine whether or not the intention of entering exists.

If a pedestrian within the monitored region (*MR*) has the intention of entering a specific region, there should be characteristics of continuous movement trajectory toward the specific exit/entrance, or looking at the specific exit/entrance with greater time accumulation, etc. Therefore, through the movement trajectory and the spatial position the pedestrians within the monitored regions, in this research the temporal and spatial cumulative probability is calculated and used to determine the intention of entering a specific region. As to the movement trajectories, those pedestrians with the intention of entering the specific region shall gradually move toward the entrance in the process. As to the spatial positions, the position closer to the entrance should be with the higher probability of intention to enter. On the contrary, the position farther to the entrance should be with the lower probability. According to the above description, the probability values of human faces based on their spatial positions within the monitored region is estimated, and then to obtain the cumulative probability in time-space to confirm whether the person has the intention of entering the specific region based on the movement trajectories of the human faces in time.

Since it cannot be predicated from where the pedestrian will enter, in order to obtain the probability of the human face in various positions in space in this research, we assume the center position (x_c^t, y_c^t) of a human face as a random variable. Thus, the movement trajectory of its center point shall have a specific probability distribution during the movement process. First we preset the movement trajectory of the pedestrian from entering the monitored region gradually moving toward the specific exit/entrance, and then according to different starting positions they can be divided into six kinds of entering conditions: upper left, upper right, right above, left, right and lower shift as shown in Fig. 2(a). Then the one-dimensional histograms for x and y and their respective probability distributions can be obtained through vertical and horizontal projection in space, such that the probability value of the human face at various position points within the monitored region can be obtained.

In order to obtain the spatial distribution of the movement trajectories, 20 sets of real movement trajectories data for each different entering condition is calculated, so there are a total of 120 sets of trajectories. Assuming the movement mode of each set is a_i, i=1,…,120, accumulate the 120 sets of movement mode into the statistical image $s = \sum_{i=1}^{120} a_i$. Then the spatial distribution characteristics of movement trajectory can be obtained as shown in Fig. 2(a). Then, the statistical images is projected onto the *x*-axis and *y*-axis in space to obtain the one-dimensional histograms of the vertical and the horizontal spatial characteristics of the movement trajectory, as shown in the blue lines in Fig. 2(b) and 2(c).

Since the one-dimensional histograms generated from the projections of *x*-axis and *y*-axis are the spatial distributions of movement trajectories in the *x*-axis and *y*-axis, this paper uses the estimation method of probability density function (*pdf*) of histogram and the nonlinear least squares curve fitting [5-6] method to estimate the *pdf* of spatial distribution of movement trajectories in the *x*-axis and the *y*-axis respectively. As shown in the experimental results, the probability density function of vertical projection approximates to Gaussian distribution with the average value μ and standard deviation σ as 150 and 1 respectively as shown in (1a). The probability density function of horizontal projection approximates to non-central chi-square distribution with the degree of freedom k as 2 and the non-centrality λ as 23 as shown in (1b).

$$s_v(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{(-(x-\mu)/2\sigma^2)} \tag{1a}$$

$$s_h(x;k,\lambda) = \frac{1}{2} e^{-(x+\lambda)/2} (\frac{x}{\lambda})^{k/4-1/2} I_{k/2-1}(\sqrt{\lambda x}) \tag{1b}$$

where the probability distribution functions of (1a) and (1b) are shown in red dotted lines in Fig. 2(b) and (c).

Through the inclusion-exclusion principle [7] of the probability theory, the probability value of human face at each spatial position point is calculated as in (2).

$$p(x_c, y_c) = s_h(x_c) + s_v(y_c) - s_h(x_c) \times s_v(y_c) \tag{2}$$

where $s_h(x_c)$ and $s_v(x_c)$ are the probability values corresponding to the center coordinates of the human face. From (2) the probability matrix (*PM*) of each position point within the monitored region can be obtained. The probability matrix also represents the counter weight values of the various coordinate positions within the monitored space. From the variation of the probability value of the probability matrix, it is observed that the corresponding probability value is larger for position closer to the specific entrance. On the contrary, the corresponding probability value is smaller for position farther away from the specific entrance as shown in Fig. 2(d). Higher gray scale values represent higher probability values.

In order to detect whether or not the movement trajectory of the pedestrian is getting closer to the specific exit/entrance, it is assumed that a pedestrian with the intention of entering will go through τ images after entering the monitored area before getting to the entrance, and the movement trajectory probability of the human face center point of the person should be $p(x_c^i, y_c^i),\ i = 1,\ldots,\tau$. Thus, the cumulative distribution function (*cdf*) [7] up to the τ-th image is described as:

$$p_{enter} = \frac{1}{\tau}\sum_{i=1}^{\tau} p(x_c^i, y_c^i) \tag{3}$$

The cumulative probability of the pedestrian up to the τ th image can be obtained by (3). If the pedestrian continues to move toward the exit/entrance gradually or continue to look at the entrance, then the cumulative probability value P_{enter} will exceed the threshold value TH_{PM}, then the intention to enter the specific region can be determined. On the contrary, if this value is smaller than the threshold value, then it's determined that the person does not have the intention to enter, and this case will be excluded. Since the intention of accessing the specific exit/entrance should be greater for the person closer to the exit/entrance, in this research we assume the region with greater than average value μ_{PM} the probability matrix as the main monitored region (*MMR*), and this average value of the probability matrix μ_{PM} will be used as the cumulative threshold value

TH_{PM} to determine if the intention of entering exists. Thus, when the pedestrian is walking toward the specific exit/entrance location gradually, the movement trajectory of the person will fall mostly in the *MMR* (as indicated in the area enclosed by red area in Fig. 2(d)), and the cumulative probability value will become higher along with the accumulation of time and with the center point of human face center approaching the specific exit/entrance. Once it exceeds the threshold value, it's determined that the intention to enter exists and the door will be opened accordingly. Otherwise, it would be determined that the intention to enter did not exist. When the pedestrian continuously looks at the exit/entry within the *MMR*, P_{enter} will exceed the threshold value along with the accumulation of time. Thus, it can also be determined that the intention of entering the specific region exists.

To avoid the pedestrians from being pinched by the closing door before entering/leaving a specific exit/entrance, a modified temporal difference method [8] is adopted to determine whether or not there are moving objects near the exit/entrance, and the determination of whether or not the pedestrian has entered/left the specific region will be used as the basis for activating the door closing procedure.

To confirm whether the pedestrian has entered/left the specific exit/entrance, 1/3 imaging area in front of the exit/entrance is preset to be the anti-pinch monitoring region (*AMG*). The temporal difference method will be used to detect the existence of any foreground within the monitoring region as the basis for activating the door closing procedure.

Temporal difference is to detect the pixel different from the previous moment *t-1* by subtracting two adjacent images in the same image sequence. When this pixel is greater than the threshold value ε, it will be determined as foreground pixel by

$$Fg_i(t) = \begin{cases} 1, & |Fr_i(t) - Fr_i(t-1) > \varepsilon| \\ 0 & , \ otherwise \end{cases} \tag{4}$$

where $Fg_i(t)$ is the foreground pixel at time *t*. $Fr_i(t)$, $Fr_i(t-1)$ are the gray scale values of position *i* in the anti-pinch monitoring region at time *t* and *t-1* respectively.

Assuming the gray scale values of images are of Gaussian distribution, we use twice the standard gray scale value $2\sigma_{t-1}^{AMG}$ of the $Fr_i(t-1)$ anti-pinch monitoring region as the threshold value ε [9] for foreground detection. In order to prevent the pedestrian from repeated entering/leaving of the specific region after entering/leaving the anti-pinch monitoring region, the door closing procedure will be activated with 2-second delay if there is no foreground detected within the anti-pinch monitoring region.

The completed function blocks of the proposed system is presented in Fig. 1.

2.3 Evaluation of system effectiveness

To evaluate the reliability of the system, the total false action probability $ER_{tot}=FRR+FAR$ is defined, while *FAR* is false acceptance rate and *FRR* is false rejection rate. They can be analyzed as follows:

Since the face detection execution speed of this system is 15 frame/second, the human face detection rate (*DR*) is 0.9, the missing rate is *DF=1-DR*. The generally acceptable door opening/closing response time *T* is 2~3 seconds. It can be derived from the above description that the probability of rejection for a pedestrian who wants to enter the door is

$$FRR = \sum_{i=FF}^{TF} C_i^{TF} P(\theta, DF)^i \times [1 - P(\theta, DF)]^{TF-i} \tag{5}$$

where *TF=(Rt*T)* represents the number of images collected within a specified time period, $FF=(Rt*T)\mu_{PM}$ represents the minimum number of times the human face must be detected, and $P(\theta,DF)$ represents the probability of missed detection of human face within the *MMR*. Under the assumption that *q* and *DF* are independent, the formula can be simplified as

$$P(\theta, DF) = P(\theta) \times DF \tag{6a}$$

$$P(\theta) = \frac{MMR}{MR} \tag{6b}$$

where $P(\theta)$ is area ratio of *MMR* within the monitored area. According to (5), if we preset the door opening response time to be 2 seconds (starting from the detection of the first face with certain distance away from the door), then the *FRR* value should be about 2.193×10^{-6}. If the door response time was set to 3 seconds, the *FRR* value would be less than 6.808×10^{-10}. Generally speaking, it takes about 2~3 seconds for a human body to move from somewhere in front of the door to the entrance to wait for the door to open. Therefore, generally the theoretical false rejection rate should be less than 2 in a million.

On the other hand, it is either the false identifications of facial characteristics (non-human face falsely identified human face) do not possess features of continuous trajectories (random occurrence), or maybe the user only passed by in front of the door. Under these two circumstances the trajectories will be removed during the tracking procedure. That is, there will be no follow-up determination of whether or not the door shall be opened/closed for that target. Therefore, *FAR* can be considered to be 0, and the total false action rate is described by $ER_{tot}=FRR$.

It is observed from the above description that false action rate of this system can be controlled within 2 in a million. Compared with the existing systems (only assuming 1/5 of the *FAR* false action rate), this system has an excellent identification accuracy rate.

3 EXPERIMENTAL RESULT & DISCUSSION

To evaluate the proposed system, A *DM365* platform of *TI*-corp. is selected to implement all the functions. The algorithms developed were programmed in *C* language and were executed under the Linux OS core. The related parameters of the prototype system are as follows: The face detection rate is 0.9. The processing speed is 15 frame/sec. The setup height is 2.2 meters. The angle of depression is 30 degrees. The left and right viewing angles of the image are both 63 degrees. Field tests were conducted in three different locations. The content of related data is presented in table 1.

The experimental results from actual field tests are shown in table 1. Among the experiments of 125 trials in 3 different locations, the number of effective opening, within the default 2 seconds value, was 124. The false rejection rate was 0.008, slightly higher than the theoretically estimated value. In the only case of failure, it was not that the door did not open, just the opening was delayed (the reaction/response time was 4 seconds). Thus, there was actually zero case when a person wanted to enter but was rejected. On the other hand, the number of false acceptance rate due to objects passing by or environmental interference was zero. It is observed that the system effectively overcomes the disadvantage of susceptibility to environmental interference among existing automatic door control systems while retaining the advantages of opening the door effectively and safely.

4 CONCLUSIONS

In this paper, an automatic control system based on the characteristics of human behavior is proposed to replace the existing automatic door control devices. Through image analysis technologies, it is capable of opening the automatic control door after accurate identification of human object with the intention to enter/exit. This way it achieves the goals of added values such as reduction of energy consumption, improved readiness rate of the equipment, and saving of the images of people who entered/exited for future references of other applications. The results of the initial field tests revealed that the developed prototype effectively accomplished the product design specification. It is truly a feasible business product.

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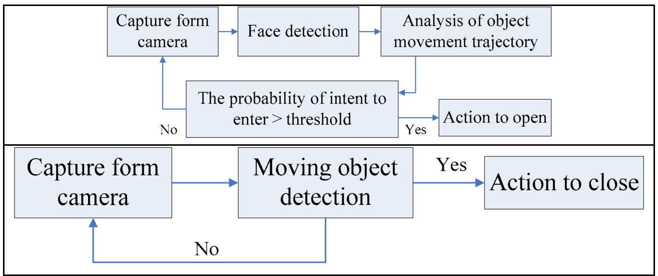
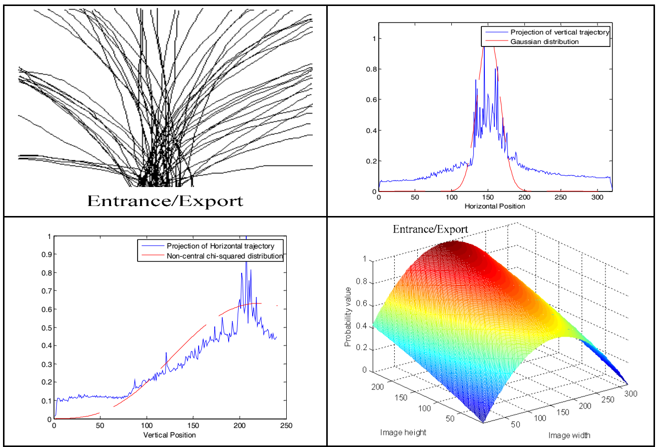


a b **Fig. 1. System flowchart of (a) door opening processes, and (b) closing processes.**



a b c d **Fig. 2. The spatial distribution of trajectory: (a) The movement trajectory, (b) its vertical projection and distribution, (c) the horizontal ones, and (d) corresponding probability matrix.**

Table 1. The False Rejection Rate Results

RESULTS\ LOCATION	TIME (HR)	NO. OF PERSONS	FAILURE COUNT	DETECTION RATE
Yangmei	3	45	0	
Banqiao	4	52	1**	
Yingge	3	28	0	
TOTAL	10	125	1	99.2%

**DOOR DID NOT OPEN AFTER THE DEFAULT TIME HAS BEEN EXCEEDED (2 SECONDS), BUT EVENTUALLY OPENED (ABOUT 4 SECONDS)