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TECHNICAL NOTE

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The Safety Helmet Detection Technology and Its Application to the Surveillance System*

ABSTRACT: The Automatic Teller Machine (ATM) plays an important role in the modern economy. It provides a fast and convenient way to process transactions between banks and their customers. Unfortunately, it also provides a convenient way for criminals to get illegal money or use stolen ATM cards to extract money from their victims' accounts. For safety reasons, each ATM has a surveillance system to record customer's face information. However, when criminals use an ATM to withdraw money illegally, they usually hide their faces with something (in Taiwan, criminals usually use safety helmets to block their faces) to avoid the surveillance system recording their face information, which decreases the efficiency of the surveillance system. In this paper, we propose a circle/circular arc detection method based upon the modified Hough transform, and apply it to the detection of safety helmets for the surveillance system of ATMs. Since the safety helmet location will be within the set of the obtainable circles/circular arcs (if any exist), we use geometric features to verify if any safety helmet exists in the set. The proposed method can be used to help the surveillance systems record a customer's face information more precisely. If customers wear safety helmets to block their faces, the system can send a message to remind them to take off their helmets. Besides this, the method can be applied to the surveillance systems of banks by providing an early warning safeguard when any "customer" or "intruder" uses a safety helmet to avoid his/her face information from being recorded by the surveillance system. This will make the surveillance system more useful. Real images are used to analyze the performance of the proposed method.

KEYWORDS: forensic science, early warning, safety helmet detection, surveillance system

The Automatic Teller Machine (ATM) is an important component of modern commerce. It provides a fast and convenient way to process economic transactions between banks and their customers. Unfortunately, it also provides a convenient way for criminals to steal money. When using an ATM, a customer will be asked to input his/her bankcard and password for personal idenification. Also, for safety reasons, each ATM is provided with a surveillance system to record customer face information. However, when criminals use an ATM to withdraw money illegally, they usually mask their faces with something (e.g., safety helmets) to avoid the surveillance system recording their face information. In most cases, criminals use safety helmets to block their faces, which decreases the efficiency of the surveillance system.

The Hough transform (HT) has been widely used for pattern detection (straight line, circle, ellipse, etc.) (1,2). The drawback of the traditional HT is the large computation and storage requirement, making it difficult for practical application. Many techniques have been provided to improve the traditional HT, such as the fast Hough transform (FHT) (3) and adaptive Hough transform (AHT) (4). They changed the processed image from one resolution into multiresolutions, and increased the efficiency of the SHT. However, the quantization error is extended in various resolution scales. Recently, the probability concept was used to modify the SHT, such as the probabilistic Hough transform (PHT) (5) and the randomized Hough transform (RHT) (6). PHT and RHT reduce the computation and the storage requirement by the probability method. However, they cannot always extract the patterns successfully, because of probability error. The modified Hough transform (MHT) for line detection (7) was proposed to relieve the probability problem of RHT and PHT. However, MHT was not proposed for circle or circular arc detection.

A method based upon the 2-D Hough transform and radius histogramming was proposed to detect circles (8). This method uses mid-perpendiculars of point pairs to obtain the centers of the circles, and computes the distance between each point and the extracted center to obtain the radius. However, this method may fail when the processed image is complicated or corrupted with noise. Besides, it is not used for circular arc detection. Pei and Horng proposed a method based on HT to detect circular arcs (9). Their method needs to execute HT computation twice: the first computation is for detecting the contours the arc lies upon while the second is for obtaining the parameters of the arcs from the near-peak HT data. However, the main drawbacks for applying the HT technique are the requirements for a huge memory storage capacity and tedious computation time. These drawbacks make HT difficult to apply in real-time detecting procedures.

In the present paper, we propose a circle/circular arc detection method (we call it the modified Hough transform) and apply it to circle/circular arc detection. Since the safety helmet location will be within the set of the obtainable circular arcs (if any exist), we use the geometric features to verify if any safety helmet exists in the set.

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Methods

The Modified Hough Transform for Circle Detection

The MHT steps for circle detection are summarized as follows:

Step 1—Seed point selection: given an image (image size $= W \times H$) with N edge points:

$$P = \{p_i = (x_i, y_i) \mid i = 1, 2, \ldots, N\} \tag{1}$$

We pick each point (p_i) from P to be the seed point. D is the distance voting space and is used to store the points whose distance to p_i is d; i.e.

$$D(d) = (x_k, y_k) \tag{2}$$

When a new seed point is selected, D is set to be *NULL*. The memory for D can be reused for the next seed point.

Step 2—Distance voting: we use distance voting to select three points that may form a circle. In Fig. 1 assume that $p_1 = (x_1, y_1)$, $p_2 = (x_2, y_2)$, and $p_3 = (x_3, y_3)$ form a circular arc and that p_2 is the midpoint of the arc. We can obtain $\overline{p_1 p_2} = \overline{p_2 p_3}$; i.e., assuming the seed point is the midpoint of a circular arc, there will exist two points whose distances to the seed point are the same. When a seed point $p_i = (x_i, y_i)$ is selected, we compute the distance (d) between p_i and the other points, p_j, in P, i.e.

$$d = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{3}$$

If $D(d)$ is *NULL*, we set $D(d) = (x_j, y_j)$; otherwise, we use these three points, p_i, p_j, and the point in $D(d)$, to obtain the circle's parameters (x_c, y_c, r_c) in the next step.

Step 3—Parameter computation: since all mid-perpendiculars formed by any two points of a circle intersect at the center of the circle, we can obtain the circle parameters (x_c, y_c, r_c) from the mid-perpendiculars.

One mid-perpendicular formed by p_1 and p_2 can be described by its slope (a_1) and the midpoint (b_1) of $\overline{p_1 p_2}$:

$$a_1 = -\frac{x_2 - x_1}{y_2 - y_1} \tag{4a}$$

and

$$b_1 = \frac{y_1 + y_2}{2} - a_1 \frac{x_1 + x_2}{2} \tag{4b}$$

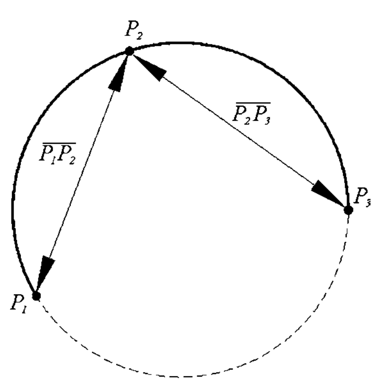


FIG. 1—*An example for three points on a circle. If there are two points,* p_1 *and* p_3*, and their distance to the midpoint,* p_2*, is the same, then these three points may form a circle.*

Similarly, the other mid-perpendicular formed by p_2 and p_3 can be described by its slope (a_2) and the midpoint (b_2) of $\overline{p_2 p_3}$:

$$a_2 = -\frac{x_3 - x_2}{y_3 - y_2} \tag{5a}$$

and

$$b_2 = \frac{y_2 + y_3}{2} - a_2 \frac{x_2 + x_3}{2} \tag{5b}$$

Since the center (x_c, y_c) of the circle formed by p_1, p_2, and p_3 is also the intersection point of two mid-perpendiculars (Eqs 4 and 5), we can obtain

$$x_0 = \frac{b_2 - b_1}{a_1 - a_2} \tag{6a}$$

and

$$y_0 = a_1 x_0 + b_1 \tag{6b}$$

The radius of the circle can be obtained by

$$r_0 = \sqrt{(x_1 - x_c)^2 + (y_1 - y_c)^2} \tag{7}$$

Step 4—Parameter voting: we set a parameter space to record the parameters from step 3. If (x_0, y_0, r_0) doesn't exist in the parameter space, we create a new record (x_0, y_0, r_0), in the parameter space,

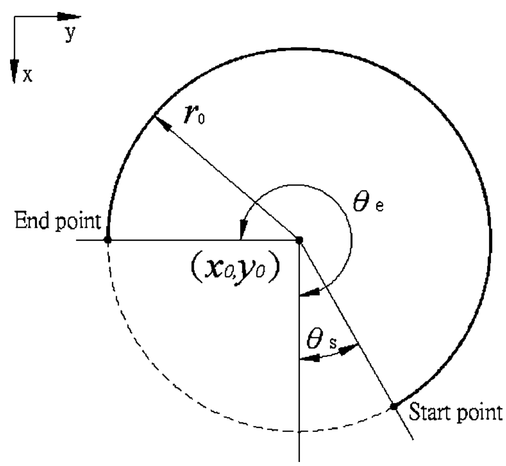


FIG. 2—*Parameters of a circular arc.*

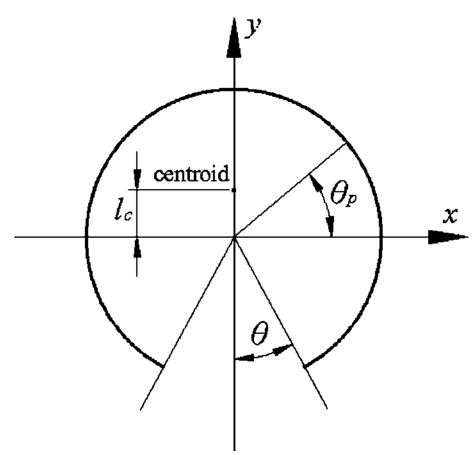


FIG. 3—*A circular arc that is symmetric about the* y*-axis.* θ *is the angle from the* y*-axis to the end point of the arc,* θ_p *is the angle from the* x*-axis to the point of the arc, and the distance from the origin to the centroid is denoted as* l_c.

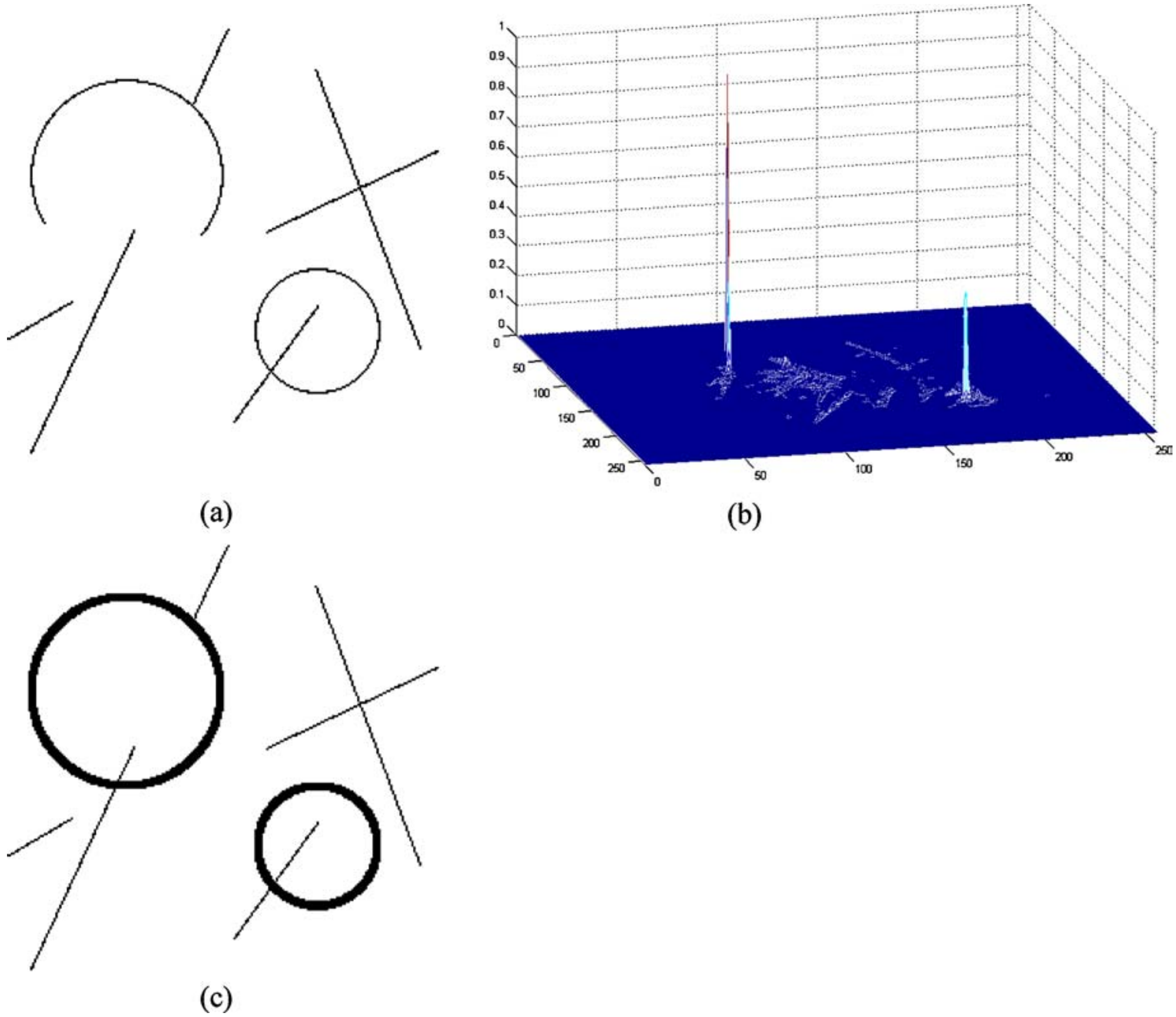


FIG. 4—*An example for the circle/circular arc detection:* (a) *original edge image;* (b) *voting result;* (c) *detection result.*

and set the initial value of the record accumulator to be 1; otherwise, we add 1 to the existing accumulator of (x_0, y_0, r_0).

If all edge points in P are picked as the seed point, the process is finished and circles in the image can be obtained from the peak position in the parameter space; otherwise, go back to Step 1.

Circular Arc Detection

If the patterns are circular arcs, they will lie on the circles found from the above circle detection steps. We apply the geometric method to estimate parameters of a circular arc. The parameters include the center coordinates (x_0, y_0), the radius (r_0), the angle of the start point to the x-axis (θ_s), and the angle of the end point to the x-axis (θ_e) (see Fig. 2).

When one set of circle candidate parameters (x_0, y_0, r_0) is obtained, we extract edge points around the circle; i.e., we take all points that satisfy

$$\left|(x - x_0)^2 + (y - y_0)^2 - r_0^2\right| \leq 1 \tag{8}$$

and put them into S (the set of points on the circular arc). The gray-level value, $f(x, y)$, is defined as the mass of the point (x, y). The centroid (x_c, y_c) of S can be defined as (9)

$$(x_c, y_c) = \left(\frac{m_{10}}{m_{00}}, \frac{m_{01}}{m_{00}}\right) \tag{9}$$

where m_{pq} is the (p, q) moment of S (10)

$$m_{pq} = \sum_x \sum_y x^p y^q f(x, y) \tag{10}$$

It is easy to see that the centroid of a circular arc and the center of the circle (that the arc lies upon) are on the symmetry axis of the arc. Without loss of generality, we let a circular arc be symmetric about the y-axis, the arc's centroid lie on the y-axis, and the center be at the origin (as shown in Fig. 3). r_0 is the radius, θ is the angle from the y-axis to the end point of the arc, and θ_p is the angle from the x-axis to the point of arc. The ratio of the arc length to the complete circle is denoted R_{ac}. The distance from the origin to the centroid is denoted l_c, and

$$l_c = \frac{\sum (mass * y_i)}{\sum mass} = \frac{\int_{-(\frac{\pi}{2}-\theta)}^{\frac{3}{2}\pi-\theta} r_0 \sin\theta_p r_0 d\theta_p}{2\pi r_0 R_{ac}} \tag{11}$$

Since $0 < R_{ac} < 1$, we can get

$$\theta = \frac{2\pi - 2\pi R_{ac}}{2} = \pi - \pi R_{ac} \tag{12}$$

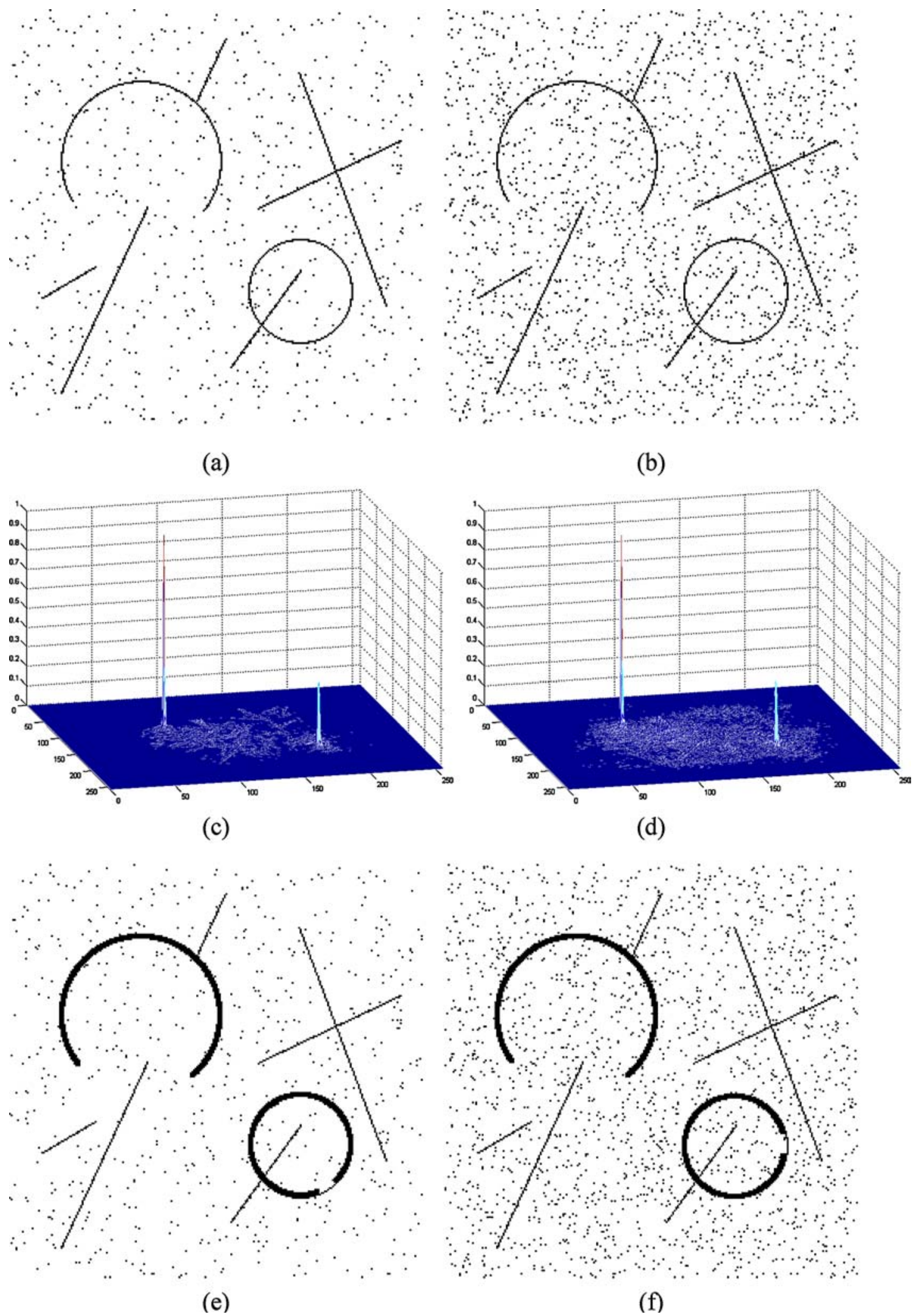


FIG. 5—*Examples for the circle/circular arc detection with noise:* (a) *original noisy image—Fig. 4*a *image with 1% noise;* (b) *original noisy image—Fig. 4*a *image with 3% noise;* (c) *and* (d) *are the voting results of* (a) *and* (b)*, respectively;* (e) *and* (f) *are the circular arc detection results of* (a) *and* (b)*, respectively.*

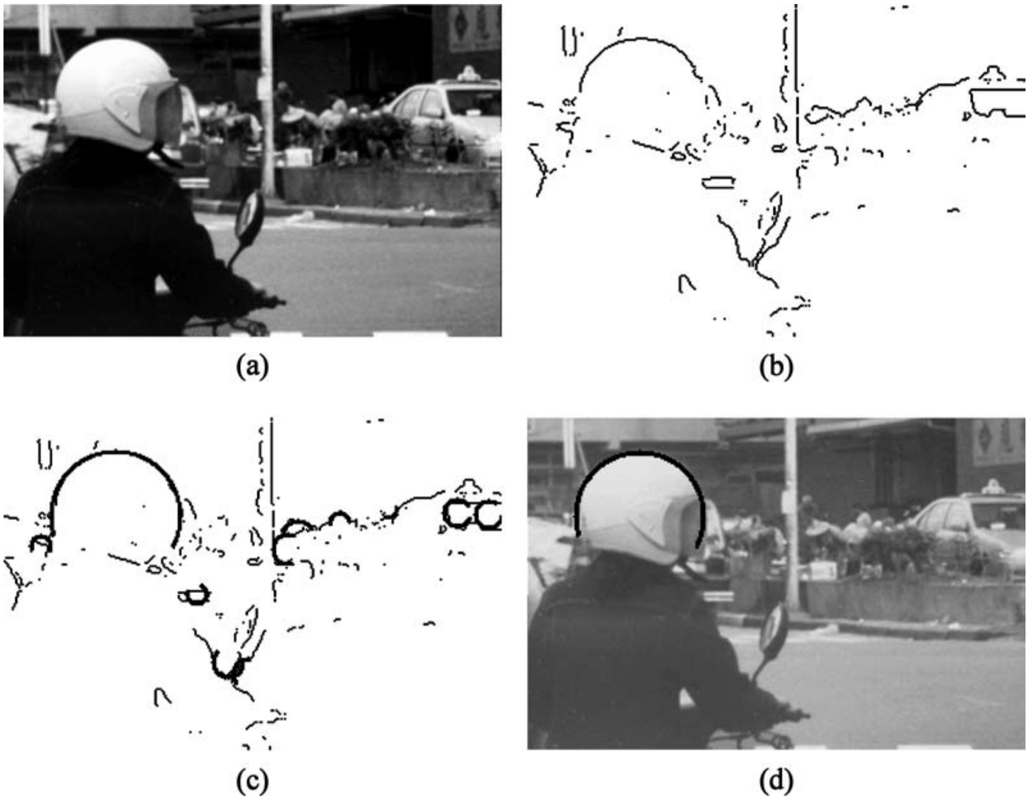


FIG. 6—*Image of a motorcyclist (with safety helmet) taken by the outdoor camera:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result* ($R_T = 0.6$, $r_T = 30$)*;* (d) *helmet detection result.*

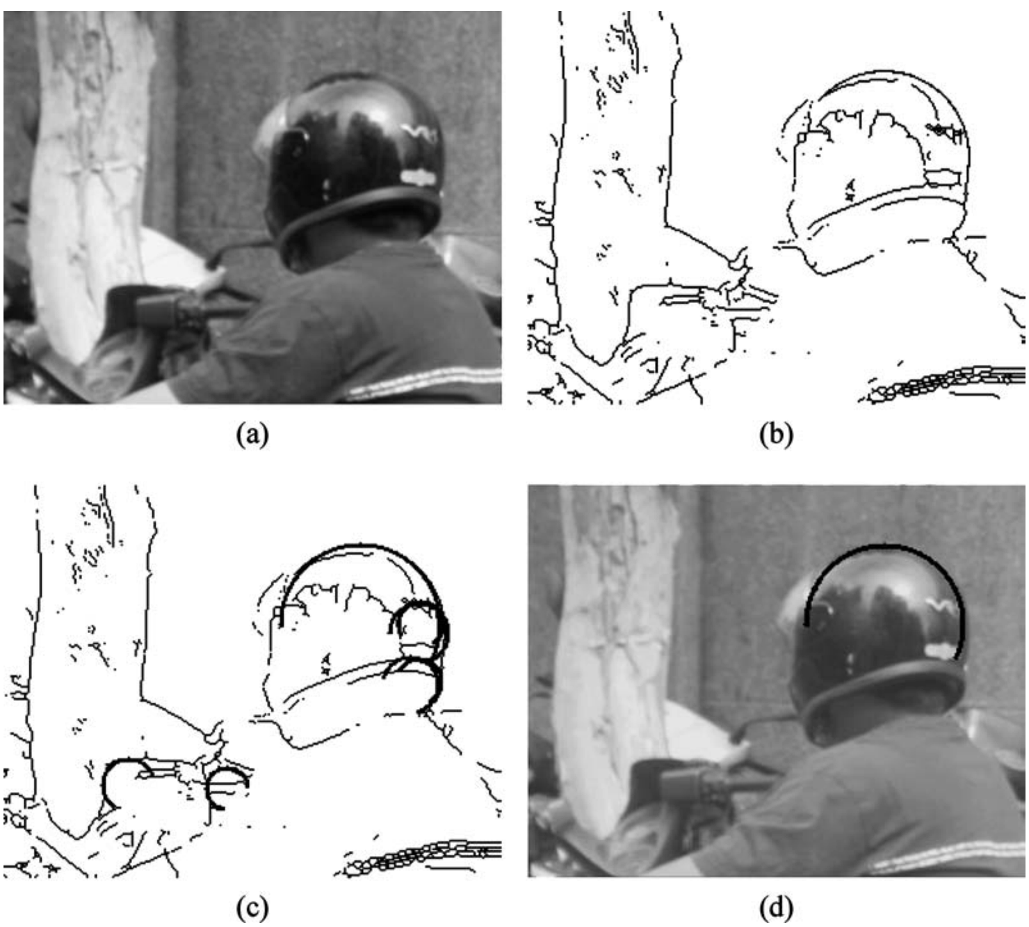


FIG. 7—*Image of a motorcyclist (with safety helmet) taken by the outdoor camera:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result* ($R_T = 0.6$, $r_T = 40$)*;* (d) *helmet detection result.*

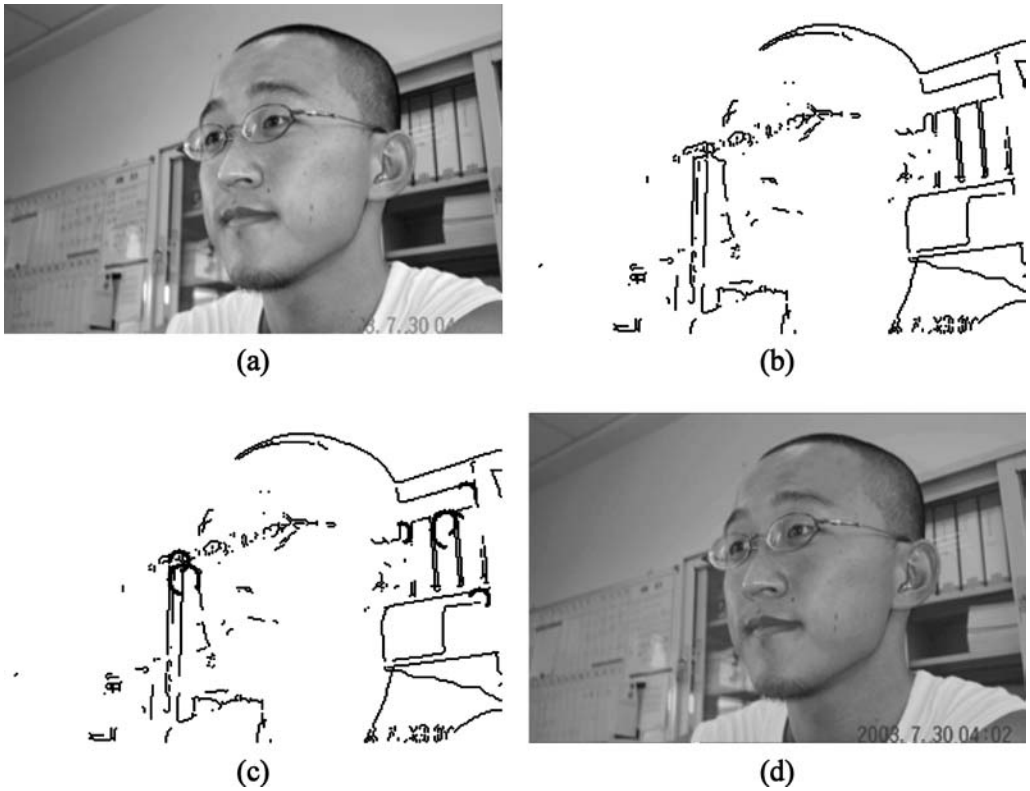


FIG. 8—*A tonsured man image for the false alarm test:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result* ($r_T = 70$)*;* (d) *detection result. From the detection results, our method can avoid setting off a false alarm for a man with little hair.*

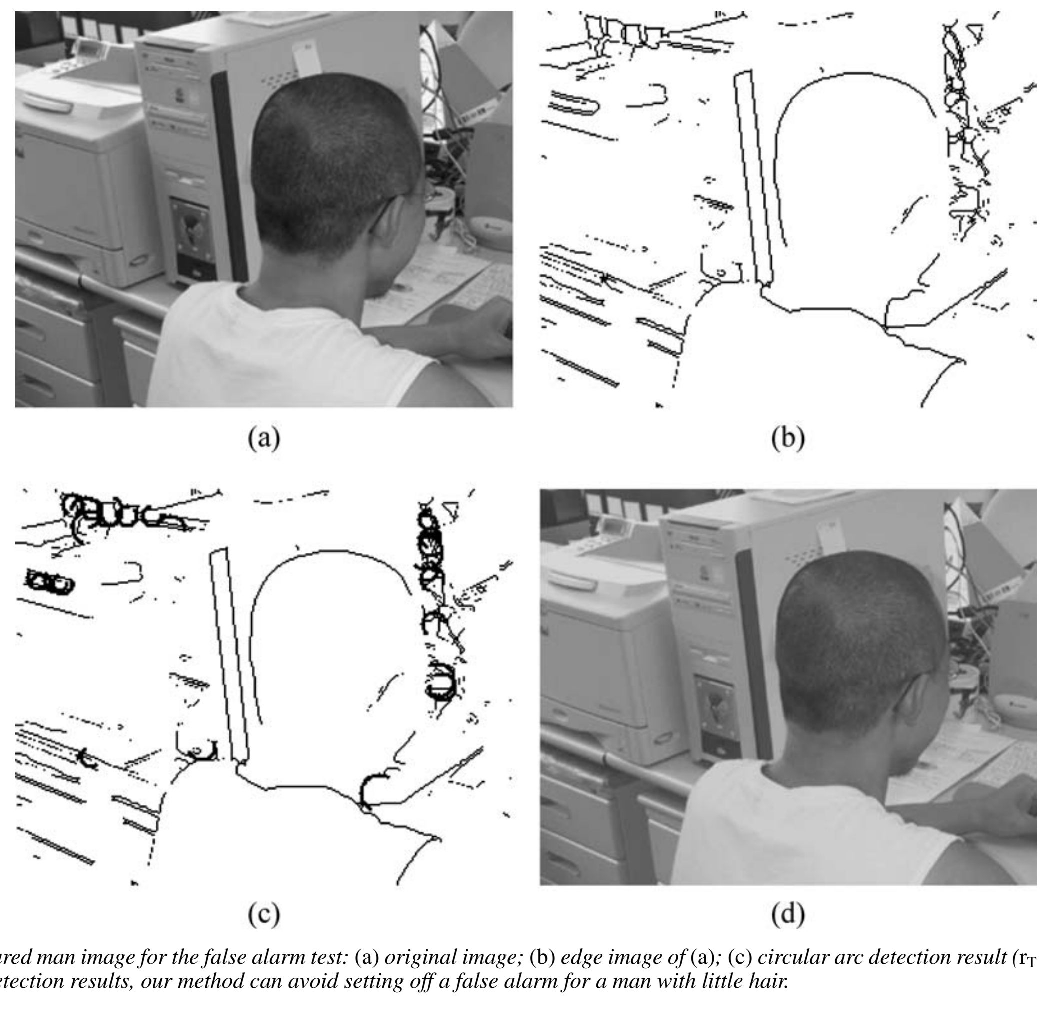


FIG. 9—*A tonsured man image for the false alarm test:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result* ($r_T = 70$)*;* (d) *detection result. From the detection results, our method can avoid setting off a false alarm for a man with little hair.*

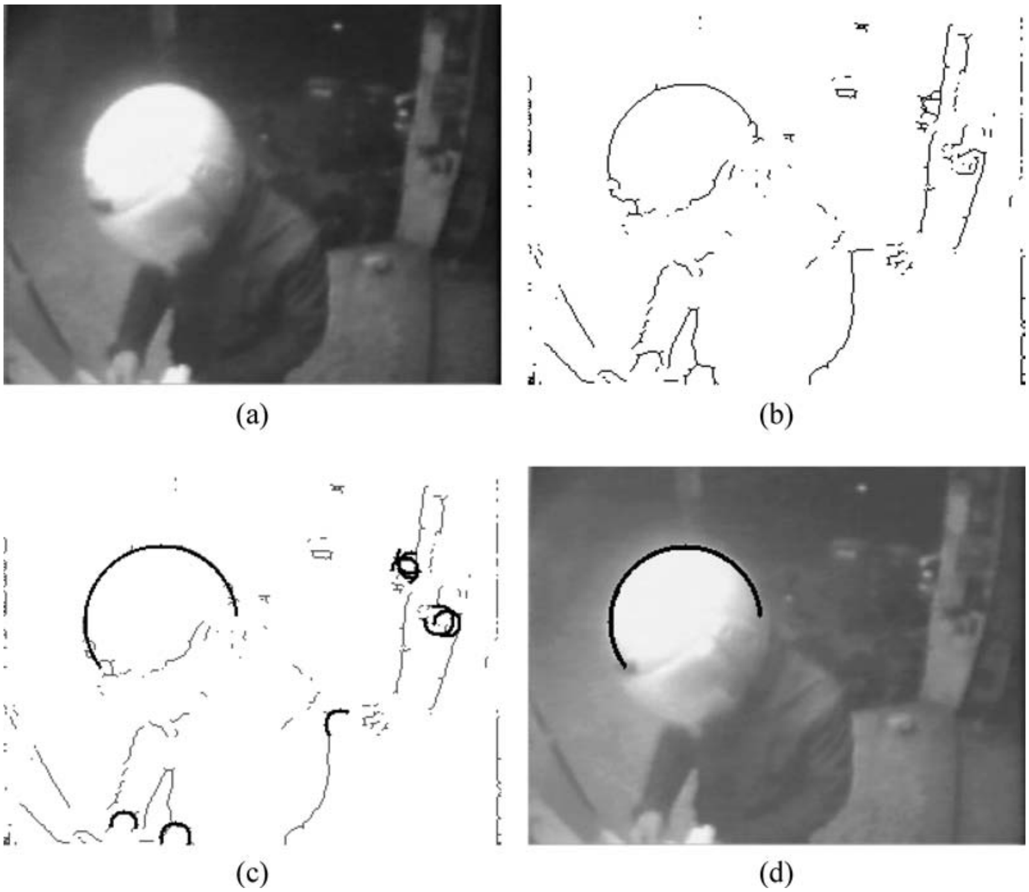


FIG. 10—*A real ATM image for helmet detection:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result;* (d) *helmet detection result.*

With Eqs (11) and (12), we can obtain the relation between l_c and R_{ac}:

$$l_c = \frac{r_0}{\pi R_{ac}} \sin(\pi R_{ac}) \tag{13}$$

When the arc is a complete circle, l_c equals zero. When the arc length is zero, l_c equals r_0. And l_c increases while R_{ac} decreases. The ideal arc length, L, can be obtained by

$$L = 2\pi r_0 \times R_{ac} \tag{14}$$

Assuming that there are m points in the set S, a circular arc can be verified while

$$\frac{m}{L} > R_T \tag{15}$$

where R_T is a predefined threshold to decide if S is a real circular arc or not. The last two parameters (θ_s) and (θ_e), can be obtained by

$$\theta_s = \tan^{-1}\left(\frac{x_c - x_0}{y_c - y_0}\right) - 2\pi \cdot R_{ac} \tag{16}$$

and

$$\theta_e = \theta_c + 2\pi \cdot R_{ac} \tag{17}$$

Safety Helmet Detection

Since the contour of a safety helmet is a circular arc, with the proposed circle/circular arc detection method we can find the positions of helmets in the image. We use the simple geometric features to verify if any safety helmet exists in the circular arcs. In the real image (taken from the ATM's surveillance system), there are many small circles/circular arcs that may be detected. In practice, since the positions of both the ATM user and the camera are fixed, the size of the helmet in the image may be estimated; that is, the detected circular arc isn't a helmet if its radius is too small. We set a predefined size threshold, r_T. If a detected circular arc satisfies the condition,

$$r_0 > r_T \tag{18}$$

the circular arc is verified as the position of the helmet.

Experiments

MHT for Circle Detection

Figure 4*a* shows an image with a circle arc and a circle where the image size is 256×256. We use the proposed MHT method to detect the circle/circular arc. When the voting process is finished, we use a voting space $f_v(x, y)$ to see the voting results in the parameter space. The size of $f_v(x, y)$ is the same as the one of the original image, and the initial values are set to be 0. For each member of the parameter space, we insert the value of the record accumulator (x_0, y_0, r_0), to $f_v(x_0, y_0)$; i.e., f_v records the voting results (edge

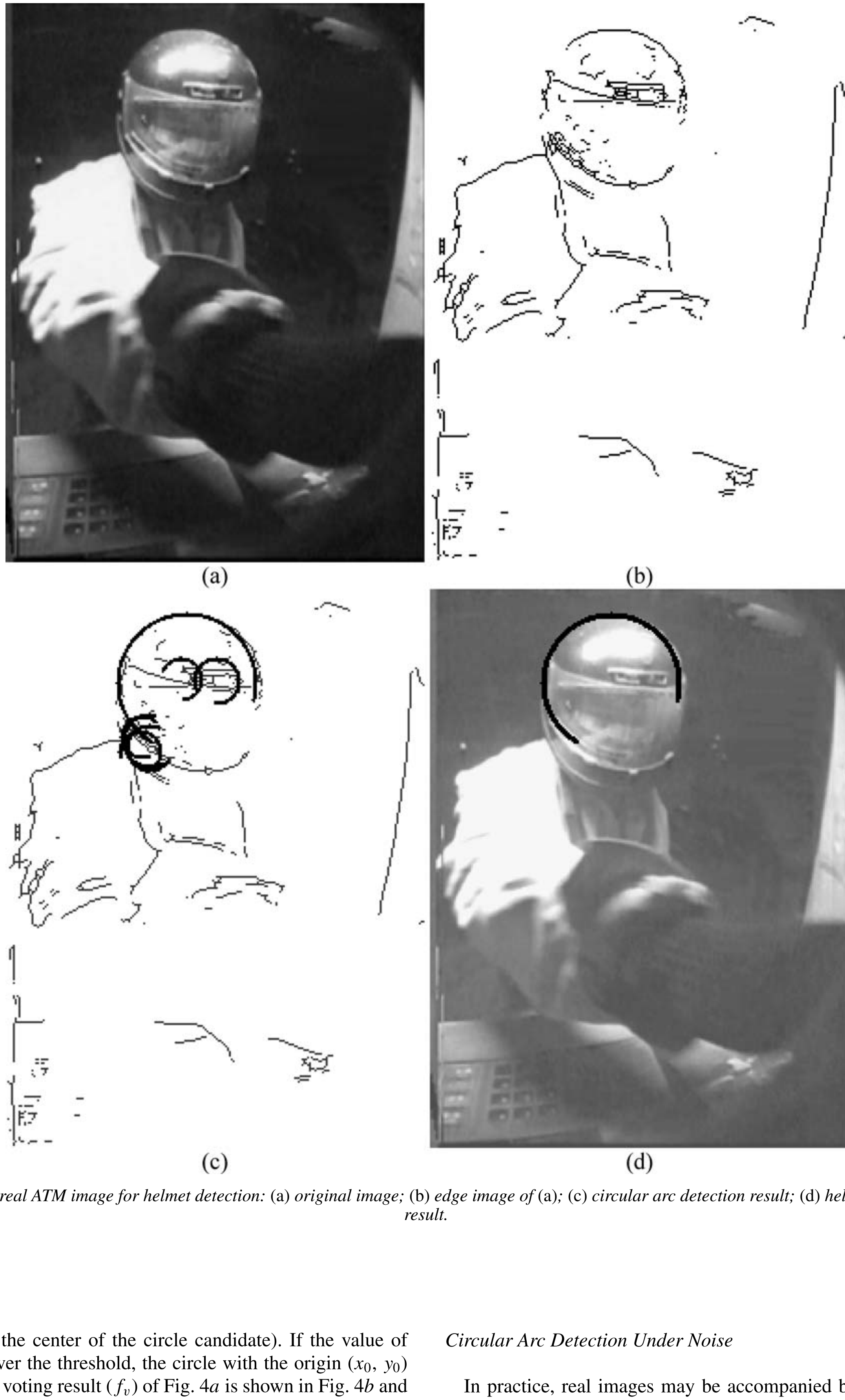


FIG. 11—*A real ATM image for helmet detection:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result;* (d) *helmet detection result.*

points vote to the center of the circle candidate). If the value of $f_v(x_0, y_0)$ is over the threshold, the circle with the origin (x_0, y_0) may exist. The voting result (f_v) of Fig. 4*a* is shown in Fig. 4*b* and the value of f_v is normalized. The circle detection result is shown in Fig. 4*c*.

Circular Arc Detection Under Noise

In practice, real images may be accompanied by noise. In this paper, we tested our method with noisy images. In Fig. 5, we added 3% and 5% pepper noise to Fig. 4*a*, and the results are shown in

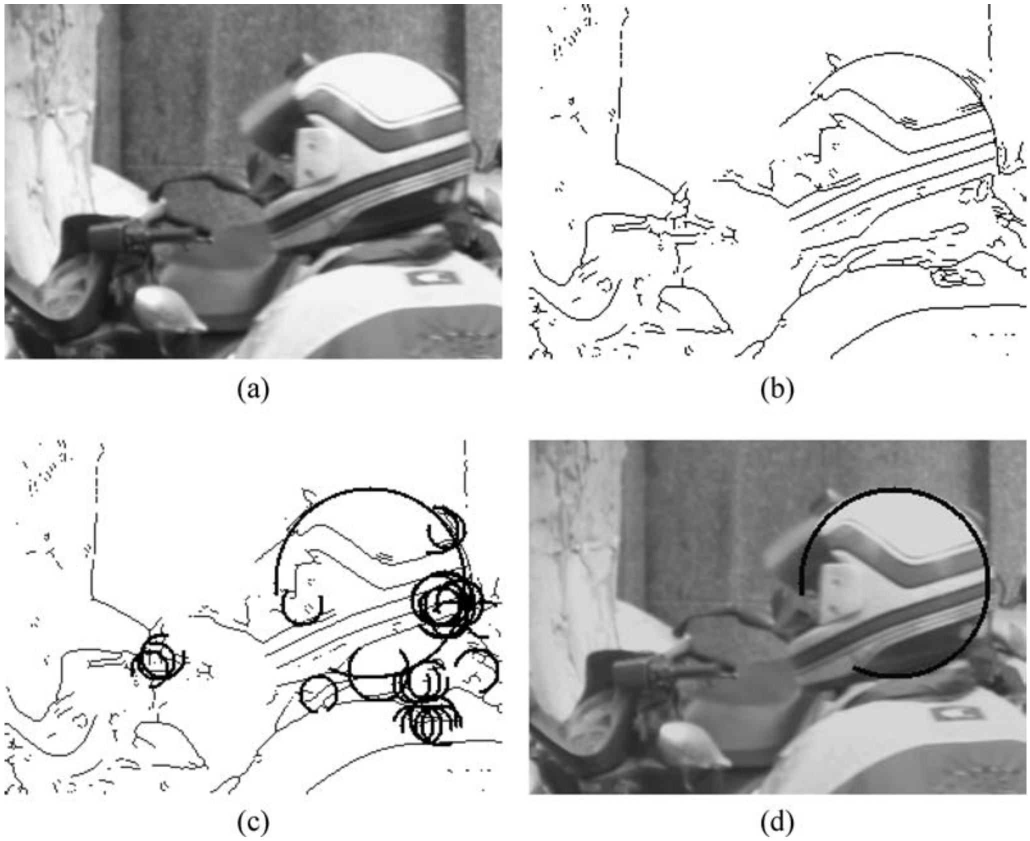


FIG. 12—*Image of a motorcyclist (with a safety helmet) taken by the outdoor camera:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result (*$R_T = 0.7$*,* $r_T = 40$*);* (d) *helmet detection result.*

Figs. 5*a* and 5*b*, respectively. We used the proposed MHT method to detect the circle/circular arc. The voting results (f_v) are shown in Figs. 5*c* and 5*d*, respectively. The circular arc detection results ($R_T = 0.8$) are shown in Figs. 5*e* and 5*f*, respectively.

Real Image Tests

Figures 6*a* and 7*a* are the motorcyclist (with a safety helmet) images taken by the outdoor camera. Figures 6*b* and 7*b* show the edge images of Figs. 6*a* and 7*a*, respectively. The circular arc detection results are shown in Figs. 6*c* and 7*c*. The parameters are ($R_T = 0.6$, $r_T = 30$) and ($R_T = 0.6$, $r_T = 40$), respectively. The safety helmet detection results are shown in Figs. 6*d* and 7*d*, respectively.

The head contour of a man with little hair may look like a circular arc. This may cause a false alarm with the proposed method. Here, we used two samples of a tonsured man to test our method. Figures 8*a* and 9*a* are the tonsured man images. Figures 8*b* and 9*b* show the edge images of Figs. 8*a* and 9*a*, respectively. The circular arc detection results are shown in Figs. 8*c* and 9*c*. The parameter is $r_T = 70$. The detection results are shown in Figs. 8*d* and 9*d*, respectively. From the detection results, our method can avoid setting off a false alarm for a man with little hair.

The samples used in the paper are all from real cases. Unfortunately, the quality is very poor (but it shows the real situation, at least in Taiwan). In order to show the capability of the proposed method under the poor-quality images (under the real situation), we use the raw images without enhancement.

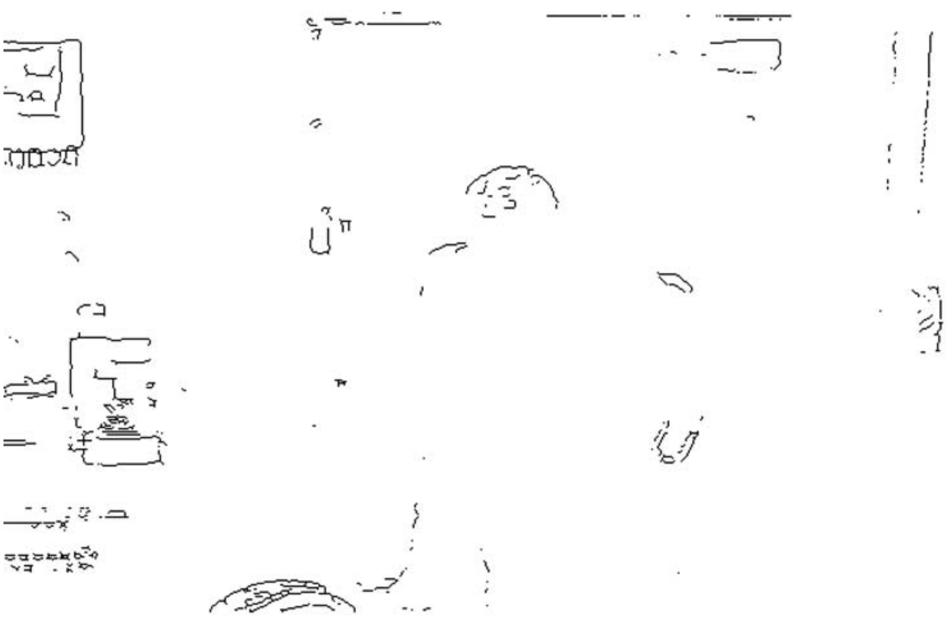
Figures 10*a* and 11*a* are real images taken from an ATM surveillance system. Figures 10*b* and 11*b* show the edge image of Figs. 10*a* and 11*a*, respectively. The circular arc detection result is shown in Figs. 10*c* and 11*c*. The helmets are detected with $R_T = 0.6$, $r_T = 35$, and the results are shown in Figs. 10*d* and 11*d*, respectively. The results show that, our method can detect the safety helmet successfully.

We use Figs. 12 and 13 to show the capability of the proposed method under more complex situations (e.g., multitoned helmets and multitoned backgrounds). Figure 12*a* is the motorcyclist (with a safety helmet) image taken by the outdoor camera. Figure 12*b* shows the edge images of Fig. 12*a*. The circular arc detection result is shown in Fig. 12*c*. The parameters are $R_T = 0.7$ and $r_T = 40$. The helmet detection result is shown in Fig. 12*d*. Figure 13*a* is an image of the bank surveillance system from a real case. Figure 13*b* is the edge image of Fig. 13*a*. Figures 13*c* and 13*d* show the circular arc detection result ($R_T = 0.3$, $r_T = 30$) and the helmet detection result, respectively.

Conclusions

In this paper, we propose a circle/circular arc detection method based upon the modified Hough transform. We use the centroid information to compute the parameters of a circular arc, and we use geometric features to verify if any safety helmet exists in the image. The proposed method can be used to help the surveillance systems of ATMs record customer face information more precisely. If customers wear safety helmets to block their faces, the system can

(a)



(b)

FIG. 13—*Image of the bank surveillance system from a real case:* (a) *original image;* (b) *edge image of* (a)*;* (c) *circular arc detection result (*$R_T = 0.3$*,* $r_T = 30$*);* (d) *helmet detection result.*

send messages to remind them to take off their helmets. Besides, the method can be applied to surveillance systems of banks, and it can provide an early warning safeguard when any "customer" or "intruder" uses a safety helmet to avoid having his/her face information recorded by the surveillance system.

Recently, commercial facial recognition systems have become more popular and have shown their capability to monitor specific suspects. They use face features (such as color and geometric information) to detect and recognize faces. However, the image quality of real cases (the current situation in Taiwan) is usually poor (as shown in this paper). It is not easy for us to extract features from those images (at least in the current situation). Besides, when someone blocks his face, the face detection system may be confused. It cannot be sure if the situation is "no one appears" or "one appears but the face detection fails." This kind of proposed technology may help the system confirm the situation.

The proposed method is based upon pattern recognition technology. In future research, we will apply this kind of pattern recognition technology to detect objects of interest in the surveillance system (e.g., CCDs, X-rays, thermo-cameras) such as "a man with mask" and "a man with weapon." That will make the surveillance system more useful.

(c)

(d)

FIG. 13—*Continued.*

Acknowledgment

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