Real-time Detection Technology Based on Dynamic Line-edge for Conveyor Belt Longitudinal Tear

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***Abstract*—We propose a method of conveyor belt longitudinal tear dynamic line edge detection based on CCD digital image processing. CCD camera captured video frames of conveyor belt at a certain frequency, we first applied median noise filtering and binarization to preprocessing the motion images of conveyor belt on the condition that they were not degenerative. Then Canny edge detection operator detected the edge point of the conveyor belt longitudinal tear and Hough transformation acquired the number of straight lines of longitudinal edge. Our approach was to calculate the length of each straight line separately and add these figures up. Finally, after calculating the length of the belt tear by comparing the proportion of the real size of conveyor belt and that in the image, the computer made warning or stop. Comprehensive experiment shows that this method can extract conveyer belt longitudinal tear edge line accurately and stably and make a quick intelligent response.**

Index Terms—conveyer belt; CCD image detection; longitudinal tear; Canny edge detection; Hough transformation

I. INTRODUCTION

Belt conveyor, especially that of long distance, high power, and high belt speed, is one the most important transportation facilities in the production of coal. The longitudinal tear is one of the major disasters in belt conveyor [1]. Great losses and accident maybe caused if it can not be found timely.

At present, there are numerous detection methods of longitudinal tear for conveyor belt, such as photoelectric sensor technology, roller bearing abnormal test and atomic physics method. Besides, conveyor abnormal current gauging, ultrasonic scanning technology and wireless transmitting sensing method are also used. However, the shortcomings of most of these methods are of immaturity, lack of real-time, more intermediate parts, costliness, too many false actions and so on. The characteristics of the detection and protection technology are process complexity, higher cost. If not handled properly, the strength of the conveyor belt will be reduced. What's more, after the tear of conveyor belt, it can not be effective until reach the action condition of the protection device. So they lacks of reliability and real-time [2].

The computer vision system is used in this paper to obtain conveyor belt running information. The video frames for belt running are acquired by computer vision system through the CCD camera. And then the image preprocessing and image analysis will be proceeding so as to achieve the information whether the conveyor belt is tearing and making intelligent decision to warning or stop [3].

II. DETECTING PROCESS

Presently the extensive use of steel-cored belt's strength to resist tensile is increased, but the intensity of resisting the longitudinal tear is not improved. And the strength is only the rubber itself. So it is prone to cause the longitudinal tear. And the direction of longitudinal tear is along the wire rope to constantly tear, which is basically one line or a few straight lines. And Hough transformation is the very important method to check the shape of border points, which can exchange the coordinate space image to change parameter space to realize the fitting of the straight line and curve line. Hough transformation to linear detect is only used in this paper.

A method of automatic recognition of conveyor belt longitudinal tear is introduced in this paper, which is

Technology Development Plan fund project of Shanxi province, CN. (20080322020)

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doi:10.4304/jcp.8.4.1065-1071

processed by median filtering and binarization. And Canny operator is applied to detect the edge point. Hough transformation is used to extract the belt tear edge lines to derive for the extent of the torn belt and then judge whether alarming or parking. Fig.1 is the detection flow chart.

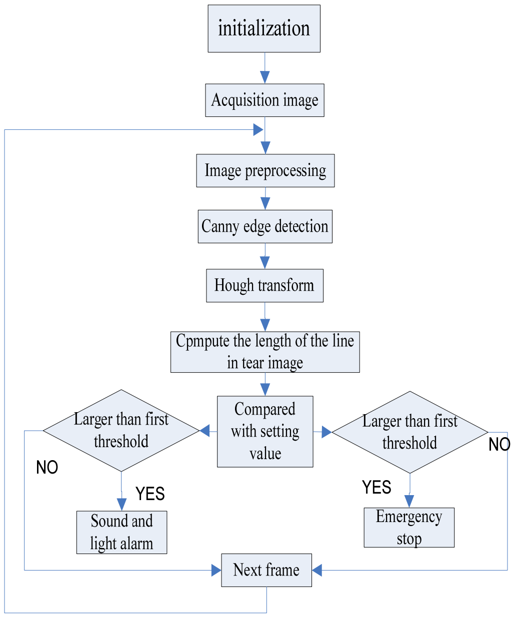

Figure 1. Detection flow chart.

III. REGRESSION MODELS OF MOVEMENT FUZZY

The CCD camera is MV-VS078FM-L 1394 interface integration industrial camera, which adopts the progressive scan black and white CCD as sensor and has the high image quality. It also has the advantages over stable signal with the output of IEEE 1394. A computer can connect several sets of industrial camera and takes up less of CPU resources. The shortest exposure time reaches to 1/10000 s and frame rate as high as 30 FPS, which meet the request of belt high speed movement photography.

Due to the relative movement between the camera and conveyor belt, this often causes the image for conveyor belt "fuzzy motion".

In all fuzzy movement, the problem of image recovery caused by uniform fuzzy movement is general and common sense. Because of the variable speed, the nonlinear motion in some conditions can be broken down to block of uniform linear movement.

Only the problem of fuzzy movement caused by uniform movement is discussed in this paper. Suppose open and close the shutter instantaneously and exposure appropriate and focus correct, $g(x,t)$ can be expressed as the integral to the actual image $w(x,t)$

$$g(x,t) = \int w(x,t)dt . \qquad (1)$$

If the scenery is static, that is $w(x,t) = f(x)$, so the above integral $f(x)$ is just the product of the time, the change of exposure time of only affect the imaging of the contrast.

But if the scenery is motive, so the folding image of exposure $g(x,t)$ as the integral of moving $w(x,t)$ with the increase of time become more blurred than before. In fact as long as put $w(x,t) = \int_0^t f(x - vt)dt$ into (1), we will get the expression which can describe the uniform motion fuzzy image's formation process:

$$g(x,t) = \int_0^t f(x - vt)dt . \qquad (2)$$

Equation (1) is the expression of uniform motion of fuzzy imaging. Equation (2) shows that motion blurred image produced by the scenery of different time in infinite multiple images into the stack.

There are different directions and speed of the relative motion between scenery and camera, so no matter using which method to recover motion blurred image, all need first to determine the two basic elements of the direction of the movement and rate between scenery and the camera, and then identify the image recovery model, this is the problem of motive parameter determination, and also the process of estimates PSF parameters.

Suppose that the image $f(x,y)$ is two-dimensional movement, $x_0(t)$ and $y_0(t)$ are the components in the x and y directions, T on behalf of the time. The total exposure of the recording medium is integral on the time after the shutter is open to close, the fuzzy image is:

$$g(x,y) = \int_0^T f[x - x_0(t), y - y_0(t)]dt . \qquad (3)$$

In (3) $g(x,y)$ is the blurred image, above is the continuous fuzzy function model caused by the relative motion of target and camera.

If the fuzzy image caused by uniform linear motion in the y direction from the scene, every point value of the fuzzy image is:

$$g(x,y) = \int_0^T f[x, y - y_0(t)]dt . \qquad (4)$$

In (4) $y_0(t)$ is the movement component in the y direction, if the total image displacement is a, and the total time is T, the rate of movement $y_0(t) = at/T$, then the above equation becomes:

$$g(x,y) = \int_0^T f[x, y - \frac{at}{T}]dt . \qquad (5)$$

For discrete images, the discretization equation is:

$$g(x,y) = \sum_{i=0}^{L-1} f(y - \frac{at}{T})\Delta t . \qquad (6)$$

In (6), L is an approximate integer of the number of pixels of pixels in the image, which is the time factor for each pixel of the impaction fuzzy. Therefore, the motion blur of the image pixel values are the product of the original image corresponding pixel value and its time cumulative.

From the point of the physical phenomenon, fuzzy motion image is actually the same belt image that after a series distance delay longer stack. If the fuzzy images that are produced by level uniform motion are simulated from the clear image. Thus, the following degenerative model can be given:

Supposed the original image of belt $f(x, y)$ along the direction of y to make similar uniform linear motion in image plane, so the degraded image is

$$g(x, y) = \frac{1}{vT+1}\sum_{i=0}^{vT} f(x, y-i) . \tag{7}$$

Among them the belt running speed is v (unit: pixel/s), the exposure time is T , then the belt's displacement within T is vT .

If the displacement of belt is less than a pixels within the exposure time, then $vT < 1$, then there is

$$f(x, y) = g(x, y) . \tag{8}$$

In this way degenerative image caused by the fuzzy motion can be ignored. Then there is:

$$T < 1/v . \tag{9}$$

When the pixels of direction y pixels is 768 and belt speed is 4 m/s and camera along the y direction for 1 m, then T < 1/3072 from (9). The exposure time of MV-VS078FM-L camera is 1/10000s minimum, which can accord with the requirement that the image is not degenerative.

IV. Image Preprocessing

A. Median Filter

There are a large number of factors in testing environment, including large dust coal and not even light source making the image with isolated group of point and line noise. The median filter is sequencing the numbers of current pixels and then the middle numerical value is assigned to the current point. Thus isolated noise points can be eliminated, and grey value of belt crack area is lower than both sides of crack. The characteristics of cracks can be highlighted by the median filter.

The principle of median filter is to replace the value of the sequence or digital images with the median value of the points of adjacent domain, the definition of median value in the sequence is:

If $x_1, x_2 ... x_n$ is the sequence, first to put it in order by size:

$$x_{i1} \le x_{i2} \le x_{i3} ... \le x_{in} . \tag{10}$$

The median y of the sequence is:

$$y = Med\{x_1, x_2 .. x_n\} = \begin{cases} x_i(\frac{n+1}{2}) & n \, is \, odd number \\ \frac{1}{2}[x_{i\frac{n}{2}} + x_{i(\frac{n+1}{2})}] & n \, is \, even numbe \end{cases} . \tag{11}$$

If the adjacent area of a specific length or shape as the window, in the one-dimensional case, the median filter is a sliding window, which contains the pixels of odd number. The middle value of the pixel in the window is replaced by the middle value of all pixels in the window. Suppose the input sequence is $\{x_i i \in I\}$, I is a subset of the natural number n is the length of the window, and set $u = \frac{n-1}{2}$, the output of the filter is:

$$y_i = Med\{x_i\} = Med\{x_{i-u} ... x_i ... x_{i+u}\} . \tag{12}$$

Equation (12) showed that the median of the points i only with the median value of the points before and after the window. y_i is the median value of the sequence x_i .

To promote the concept of median filter of to two dimensions, and use some form of two-dimensional window. Two dimensions median filtering can be defined as follows:

Set $\{x_{ij}, (i, j) \in I^2\}$ are the gray value of digital image, filter window is A, y_{ij} is the median value of x_{ij} in the window A, then,

$$y_{ij} = Med\{x_{ij}\} = Med\{x_{(i+r),(j+s)}, (r, s) \in A, i, j \in I^2\} . \tag{13}$$

Equation (13) is the median value expression of x_{ij} in window A, two dimensions median filtering window can take the square, and also take the quasi-circular or cruciform[4].

B. Binary Image

After the median filtering is to binary processing, namely select a suitable threshold, which will convert image to black and white binary image. If the pixel gray scale value of image is greater than the threshold, the pixel grayscale value sets to 255, otherwise the grey value sets to 0. There is no grey value among the transition [5].

We select the maximum variance threshold in this article, which also known as the Otsu threshold that proposed by Otsu in 1980, Japan, which is derived on the basis of the difference between the least squares method.

The histogram is cut into two groups in the disposition of a certain threshold, when the variance of the two groups is to the maximum, we decide the threshold. Set the gray-scale level of images collected is $1 \sim m$, the pixel of gray value i is n_i , then get:

The total Pixels is $N = \sum_{i=1}^{m} n_i$

The probability of each gray value is $p_i = \frac{n_i}{N}$

Then using T split it into two groups $C_0 = \{1 \sim T\}$ and $C_1 = \{T+1 \sim m\}$

The probabilities of each group are as follows:

The probability of C_0 produced for

$$w_0 = \sum_{i=1}^{T} p_i = w(T)$$

The probability of C_1 produced for

$$w_1 = \sum_{i=T+1}^{m} p_i = 1 - w_0$$

The average of C_0 is

$$\mu_0 = \sum_{i=1}^{T} \frac{ip_i}{w_0} = \frac{\mu(T)}{w(T)}$$

The average of C_1 is

$$\mu_1 = \sum_{i=T+1}^{m} \frac{ip_i}{w_1} = \frac{\mu - \mu(T)}{1 - w(T)}$$

$\mu = \sum_{i=1}^{m} ip_i$ is the average of overall image gray average:

$\mu(T) = \sum_{i=1}^{T} ip_i$ is the average of the threshold T, so all the gray average for sampling is $\mu = w_0\mu_0 + w_1\mu_1$, the variance of two groups can find out by next formula:

$$\delta^2(T) = w_0(\mu_0 - \mu)^2 + w_1(\mu_1 - \mu)^2 = w_0 w_1 (\mu_1 - \mu_0)$$
$$= \frac{[\mu w(T) - \mu(T)]^2}{w(T)[1 - w(T)]} \qquad (14)$$

From $1 \sim m$ to change T, we got the value T^* of $\max \delta^2(T)$, then T^* is the threshold, $\delta^2(T)$ is the threshold selection function, this method is the optimal automatically threshold selection method [6].

V. CANNY EDGE DETECTION

In the image edge detection, reducing the noise and edge accurate location is unable to satisfy simultaneously. Some edge detection algorithm through the smoothing to remove the noise while it also increases the uncertainty of the positioning for the edge at the same time. It is not only improving the edge detection operators on the edge of the sensitivity, but also improving the sensitivity to noise. Canny operator is the best compromise method to improve resistance of noise and accurate location [7]. From the quality of Canny edge detection, the following three criteria are proposed in this paper.

1) The signal-to-noise ratio (SNR) criterion: The error rate to detect the edge must be as low as possible and the image edge of the real as far as possible and reduce the false detection to get a good result. That is to make the signal-to-noise ratio (SNR) as large as possible in mathematics. The greater the SNR, the smaller the error rate:

$$SNR = \frac{\left| \int_{-\omega}^{+\omega} G(-x) f(x) dx \right|}{n_0 \left[\int_{-\omega}^{+\omega} f^2(x) dx \right]^{\frac{1}{2}}} \qquad (15)$$

In (15) $f(x)$ is the impulse response of limited filter for the boundary of $[-\omega, +\omega]$, $G(x)$ represents the edge, n_0 is the RMS of Gaussian noise.

2) Location accuracy criterion: The edge detection is as close as possible to the real edge. That is to seek filter function $f(x)$ to make Loc as large as possible in mathematics.

$$Loc = \frac{\left| \int_{-\omega}^{+\omega} G'(-x) f'(x) dx \right|}{n_0 \left[\int_{-\omega}^{+\omega} f'^2(x) dx \right]^{\frac{1}{2}}} \qquad (16)$$

Among it, $G'(-x)$, $f'(x)$ it is respectively the first derivative of $G(x)$, $f(x)$.

3) Single edge response criterion: There is low response to the same edge, that is to say, only one response is best to single edge. The average distance between the maximum values of filter to the edge response:

$$d_{\max} = 2\pi \left[\frac{\int_{-\omega}^{+\omega} f'^2(x) dx}{\int_{-\omega}^{+\omega} f''^2(x) dx} \right]^{\frac{1}{2}} \approx kW \qquad (17)$$

So in the width of 2W, maximum number is:

$$N = \frac{2W}{kW} = \frac{2}{k} \qquad (18)$$

Obviously, as long as fixed K, the maximum number is fixed.

With the three criteria, to find the best filter problem is transformed to constraint optimization problem in function. The solution of the formula can be approached by Gaussian derivative. The basic idea of Canny edge detection is choosing the Gaussian filter to smoothing filter of the image, and then using the extremum inhibition technology to get the last of the edge image [8]. The procedures are:

Use the template of Gaussian filter to convolute with the original image to eliminate noise.

Utilize derivative operator to find the derivative of image grey along two of the direction, and get the gradient size:

$$|G| = \sqrt{G_x^2 + G_y^2} \qquad (19)$$

Gradient direction:

$$\theta = \arctan\left(\frac{G_y}{G_x} \right) \qquad (20)$$

Non-maxima suppression of the gradient amplitude: To determine the edge must be retained the biggest point of local gradient, which is setting non-maxima value points to zeros in order to get the edge of refinement.

Use double threshold algorithm to detect and link the edges: Using two thresholds T_1 and T_2 ($T_1 < T_2$), so they can get an image of two thresholds edge $L_1[i, j]$ and $L_2[i, j]$. Since the image $L_2[i, j]$ can be derived with the use of high threshold, there is little fake edge but there are stopping (not closed). Double threshold values method is to link the edge to outline of $L_2[i, j]$. When the end of the outline got, the algorithm sought the edge that can be connected to the contour at the adjacent 8 points in $L_1[i, j]$. In this way, algorithm is collecting edge constantly until link up $L_2[i, j]$. T_2 is used to find every line, T_1 is used to find the fracture of the edge in these lines of two directions so as to connect the edges.

Fig.2 is a processed belt image by Canny operator.

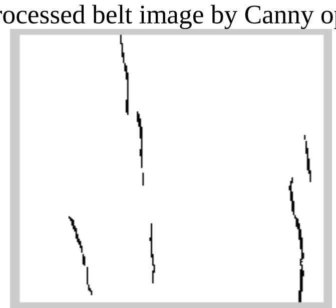

Figure 2. Processed belt image by Canny operator.

VI. Detecting Tear By Using Hough Transformation

A. Hough Transformation Theory

In 1962, the method of detection straight line of images are put forward by Paul Hough according to math dual principles, which mainly used in binary image of linear testing. Hough transformation is a description method for the line, which exchanges the space line in Cartesian Coordinates to the point in the space of Polar Coordinates [9]. Fig.3 (a) is a straight line in Cartesian Coordinates, if ρ represents the distance from the line of origin to the straight line, θ is the angle from x axis line to the normal. The straight line can be described by following parameter equation. The Hough transformation of linear line is:

$$\rho = x\cos\theta + y\sin\theta \tag{21}$$

Fig.3 (b) (ρ, θ) shows the point in Polar Coordinates, in which the x-coordinate is the angle θ of normal to the line, and the y-coordinate is the distance ρ from the line of origin to the straight line. In Cartesian Coordinates, a bunch of line (as it is shown in Fig.3 (c)) through the public point is mapped to the Polar Coordinates is a point sets, which constitute a curve. Actually this is sine curve (Fig.3 (d)). So a single point in Cartesian Coordinates space is corresponding to the Polar Coordinates in a sine curve [10].

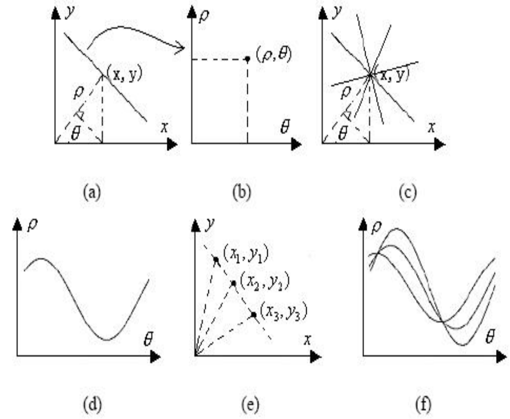

Figure 3. Hough transformation principle.

The points which are coplanar in Cartesian Coordinates (as show $(x_1, y_1)(x_2, y_2)(x_3, y_3)$ in Fig.3 (e) in the common line) are mapped to the Polar Coordinates system, which is a cluster of curve in the total points (Fig.3 (f)). It can be seen that this three curves have two points of intersection, actually this two interaction points of the corresponding x-axis value namely the normal angle differ 180º, is the same straight lines corresponding to Cartesian Coordinates. If the range of normal angle for the linear line is $-\frac{\pi}{2} < \theta < \frac{\pi}{2}$, the intersection is only one. It can be seen that a corresponding relation of different lines and points is established by Hough transformation in Fig. 3.

B. The Method to Realize Hough Transformation

The data in the computer memory collected by CCD camera are different from the location of the longitudinal tear in the image processed by binary. The identification of the shape and the size of the cracks have certain difference. Thus the common point of the tear image can be shown that there are more or less, or thick or thin one or a few straight lines after the extraction to edge of tear image. The core of the algorithm is the linear detection. The following introduced is Hough transform linear of detection algorithm principle. As it is shown in Fig.4, a dot represents an image of a pixel, M (i, j) for the mark of that point.

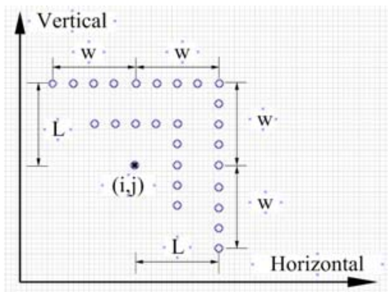

Figure 4. The schemes of the pixels processed by linear detection algorithm.

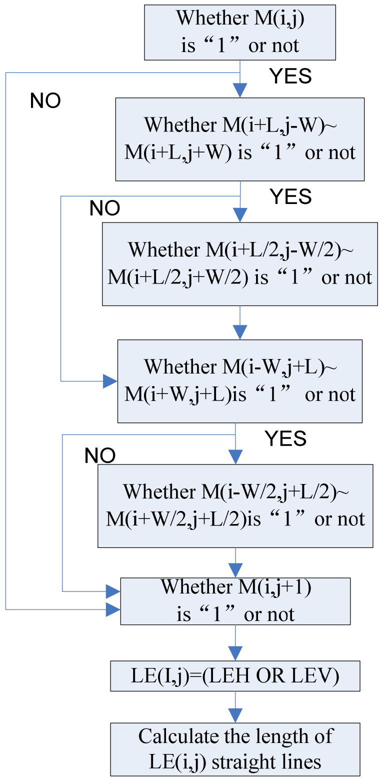

Figure 5. Linear detection algorithm flow chart.

Fig.5 shows linear detection algorithm flow chart. Image processing started from (0, 0) pixel, from left to right, from the bottom to the top process each pixel. Taking black point pixels (i, j) for instance, each pixel processing is according to the parameters for of L、W, testing the adjacent point above the black point at first, and then on the right side of the black point. As long as detecting the straight line (mark LVE for true or LHE for true) in a direction, in this way, judging (i, j) is located in a straight line. Setting LE is true. Thus the straight line number detected to must add one [11]. And then calculating the length of each line to summate, a real belt size proportion to compute belt length is compared with so as to warn or park.

It can be seen that W, L is to control the precision of linear precision (Figure 4 shows that W = L, W, L can take a different value). Generally, W/L need to less than 1 (more than 1 can produce some redundant judgments). When W/L come to large the curve detection may not be the approximate linear; When W/L come to small, the straight line detected is more closer to real straight line, that is to say the points around (i, j) which deviated more and part of the large slope are not be detected, but it can not effect processing results, because after the extraction of the images, the majority of tear image is straight line which is consistent with the running direction of belt line. Linear detection Hough space is shown in Fig.6. Testing of line segment is shown in Fig.7 below[12].

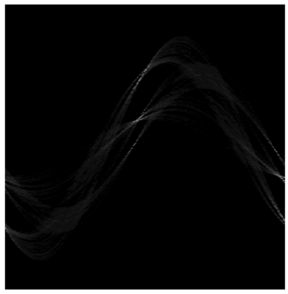

Figure 6. Hough space.

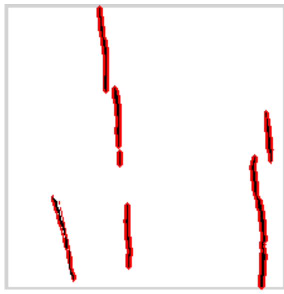

Figure 7. Testing out the line segment.

VII. Conclusion

A method of conveyer belts longitudinal tear dynamic line edge detection is presented based on CCD-digital image processing in this paper. It can be shown that the whole system proves the strong anti-interference, fewer false action, and high reliability in the experiments. Several features of longitudinal tear image in conveyor belt are concluded which are: ①the number of pixels tear area is much lower than the background pixel number. ②the grey value is much lower in the area of belt crack than that of background image. ③the Gray-level histogram of belt image shows the single-peak property obviously. ④crack is parallel to the running direction of conveyor belt and linear.

The dynamic edge detection method can monitor and warn the running conditions of conveyor belt timely and stop the further of expand the longitudinal tore accident. It is good for enterprise to provide enough security in practical production and avoid accident effectively.

Acknowledgment

This subject roots in the Technology Development Plan fund project of Shanxi Province, CN. (20080322020)

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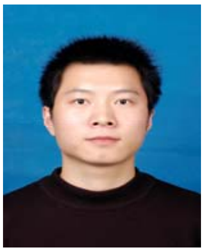

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