Journal of Southeast University (English Edition) Vol. 31, No. 4, pp. 553 – 558 Dec. 2015 ISSN 1003—7985

Detection of broken manhole cover using improved Hough and image contrast

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Abstract: The damage or loss of urban road manhole covers may cause great risk to residents' lives and property if they cannot be discovered in time. Most existing research recommendations for solving this problem are difficult to implement. This paper proposes an algorithm that combines the improved Hough transform and image comparison to identify the damage or loss of the manhole covers in complicated surface conditions by using existing urban road video images. Focusing on the pre-processed images, the edge contour tracking algorithm is applied to find all of the edges. Then with the improved Hough transformation, color recognition and image matching algorithm, the manhole cover area is found and the change rates of the manhole cover area are calculated. Based on the threshold of the change rates, it can be determined whether there is potential damage or loss in the manhole cover. Compared with the traditional Hough transform, the proposed method can effectively improve the processing speed and reduce invalid sampling and accumulation. Experimental results indicate that the proposed algorithm has the functions of effective positioning and early warning in the conditions of complex background, different perspectives, and different videoing time and conditions, such as when the target is partially covered.

Key words: manhole cover; edge tracking; improved Hough transform; shape detection; image contrast

doi: 10.3969/j.issn.1003 – 7985.2015.04.021

The manhole cover is essential to any city. There are typically a large number of manhole covers in a city which are difficult to manage and monitor. Once a manhole cover is damaged but not dealt with timely, it will bring great hidden dangers to the lives, property, or safety of people. Prasad et al.[1] used the edge curvature to determine the edge based on the traditional Hough transform method, which searches each edge profile in the area and makes a grouping calculation based on the conditions of the edge contour to determine the elliptical shape. However, this method is limited by the standard elliptical contour; therefore, it cannot be used on the shape detection of broken and damaged elliptical manhole covers. Kasemir et al.[2] proposed a detection algorithm for the elliptical shape in a high noise level image. The algorithm combines the improved Hough transform and the genetic algorithm. However, we need to design a novel algorithm that synthesizes the improved Hough transform and image comparison for solving different technical problems; so it is difficult to generalize this algorithm for the detection of the broken manhole covers. Wei et al.[3] developed a detection method on the incomplete elliptical image in strong noise environments based on the iterative randomized Hough transform (IRHT). The IRHT method iteratively applies the randomized Hough transforms, constantly adjusting the iterative parameter and repeatedly amplifying the target curve by using image space and parameter space. Due to the fact that the core of this method is the iterative computation, it is time and computer memory demanding, and thus its adaptability for moving vehicles is poor in dynamic environments. Much research has been done on the manhole cover, but the research mainly focuses on manufacturing intelligence, by which a timely alarm can be set if the manhole cover is damaged. Although this method can effectively monitor the manhole cover, the implementation process of these measures requires extensive human and material resources, which will be very expense. Since a large number of manhole covers need to be maintained, there will be a great resistance for the application of manufacturing intelligence[4]. In recent years, many cities have established municipal video monitoring networks. Therefore, using existing video surveillance networks, and the image acquisition and processing technology of computer vision, we develop a method to monitor the manhole covers and raise alarm in time when there are missing and broken manhole covers. This can achieve the aim of monitoring manhole covers without any hardware investment and repetitive construction.

Usually, very complex images can be taken by cameras with a complex background, but people are often interest-

Received 2015-01-20.

Biographies: Zhang Fengyan(1972—), doctor, male, zhangleike@126.com; Guo Xiucheng (corresponding author), male, doctor, professor, seuguo@163.com.

Foundation item: The Natural Science Fundation of Education Department of Anhui Province (No. KJ2012B051).

Citation: Zhang Fengyan, Chen Rongbao, Li Yang, et al. Detection of broken manhole cover using improved Hough and image contrast[J]. Journal of Southeast University (English Edition), 2015, 31(4): 553 – 558. [doi: 10.3969/j.issn.1003 – 7985.2015.04.021]

ed in a particular region of the image with special characteristics, which is the target area. It is necessary to extract the target area from the original image to further identify and analyze the target. This paper focuses on identifying the manhole cover region with more clear geometric features and computational geometry characteristics. Hence, compared with other spatial invariance features, calculating geometric features is more simple and convenient[5], and with the help of the colour recognition algorithm, it can better meet the requirements of accuracy and real-time. Therefore, we select the geometry features and colors of the manhole cover as the positioning method to contrast the images and detect manhole cover breakage.

1 Overall Scheme

The manhole cover in the image can be viewed approximately as the distortion of ellipses. The recognition of the manhole cover is to determine the region[4] and position of the manhole cover with edge curves calculated by the image processing algorithm. The Hough transform is not sensitive to image noise, and it easily conducts parallel processing and convenient for handling characteristics when images are covered locally. Therefore, it is more suitable for the elliptical extraction of the manhole cover image with complex backgrounds[5-6]. However, the traditional Hough transform has several limitations:

1) It requires a large amount of computation. For linear, the algorithm complexity is $O(n^2)$; for circle and ellipse, the algorithm complexities are $O(n^3)$ and $O(n^5)$, respectively.

2) It needs a large CPU memory.

3) The parameters extracted by quantization have interval constraints of parameter space, so it is difficult to meet high precision and real-time requirements.

Therefore, conducting an elliptical traditional Hough transform directly in the image with complicated background is not feasible[7]. In order to overcome the limitations of the traditional Hough transform, this paper first conducts the edge search to find the edges above all the image and stores them in the image list. Then we divide them into each sub image which is transformed by Hough. This can reduce the noise influence to a great extent and reduce invalid image accumulation. Also, the space of the Hough transform and time consumption are reduced to meet the system's high precision and real-time requirements. Due to the interference from other elliptic objects[8-10], the road condition is very complex. So this paper combines the color recognition and image alignment algorithm to recognize and localize the manhole cover, which can greatly improve the identification accuracy of the manhole cover.

As shown in Fig. 1, the method mainly consists of four parts: pre-processing, contour extraction, target localization and identification, and detecting suspected damage. In order to ensure an accurate extraction of the target region, before positioning, it is necessary to do some preprocessing operations such as brightness and contrast adjustment, smoothing, and denoising and edge detection. Then we search the edge, delete the useless contour, extract the useful contour, and recognize and localize the manhole cover by the improved Hough transform and the color recognition algorithm. Finally, the image matching algorithm is used to calculate the suspected discrimination by the change rate.

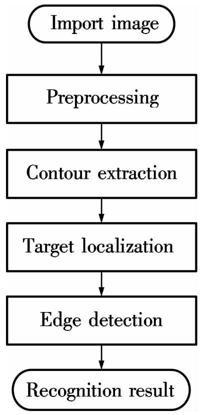

Fig. 1 The process of the proposed method

2 Identification and Localization of the Manhole Cover

Since images are affected by acquisition conditions such as illumination uniformity and the time period, we need to carry out image preprocessing, which mainly includes the adjustment of brightness, equalization and smoothing of the contrast histogram, the denoising method of mathematical morphology and the detection of Canny edge[11]. These preprocessing algorithms are classic approaches, which are not focused on in this paper.

2.1 Edge tracking

In order to analyze the shape of the collected image, we need to find edge points of the target and then connect the edge points into one continuous boundary for boundary tracking. As shown in Fig. 2, the specific steps are as follows:

1) Set a discontinuous reference distance "gap", establish a two-dimensional image array I (store two images after binaryzation) and a dynamic two-dimensional array "cur" (coordinate storage of edge point).

2) Scan a two-dimensional array I of an image from top to bottom and from left to right, save the point on the left side of A_0 after locating the edge point $A_0(x_0, y_0)$ in the array "cur", and set $A_0(x_0, y_0)$ to correspond to the coordinate point $I(x, y) = 0$ in the I array, showing that the point has been recorded.

3) Scan the local window $[x - \text{gap}, x + \text{gap}] \times [y -$

gap, y + gap] centered by coordinates (x, y) in the image I from top to bottom and from left to right, and seek the nearest edge point A_1 to point (x, y). If A_1 exists, then record A_1 for coordinates (x, y) and repeat Step 3), until no edge points can be found. Denote edge points $A_e(x_e, y_e)$. It should be noted that in Step 3) the tracking edge contour is carried out only in one direction.

4) $A_0(x_0, y_0)$ is regarded as the starting point coordinates. Set $(x, y) = (x_0, y_0)$, repeat Step 3), and the end point coordinate is denoted as $A_s(x_s, y_s)$.

5) If there are n lines of continuous edge in the images, repeat Steps 2) to 4) and produce a closed edge point set. The corresponding edge point set is $\{cur(i), i = 1, 2, \dots, n\}$.

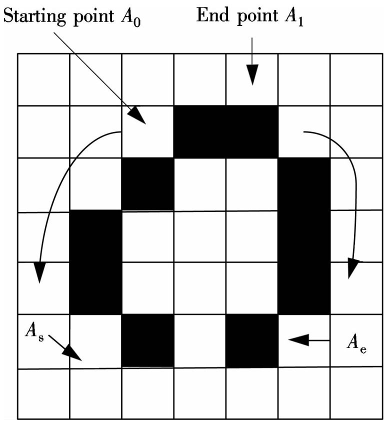

Fig. 2 The schematic of edge tracking

2.2 Elliptic automatic recognition

Among a plurality of edge point set boundaries calculated by the edge tracking algorithm, there is the elliptic boundary of the manhole cover and other interfering boundaries. To distinguish the target boundary from the boundaries, we need to recognize the elliptical objects. The camera angle is different, so the manhole cover in the image will stretch and distort to a different elliptic according to a certain angle, that is, an oblique ellipse with a certain included angle existing in the direction of the main shaft and the X shaft. The standard equation of the ellipse is

$$\frac{(x-x_0)^2}{a^2}+\frac{(y-y_0)^2}{b^2}=1 \tag{1}$$

In the actual situation, the axis of the elliptical image of the manhole cover is not parallel to the coordinate axes and can be approximately seen as translation and rotation.

Also, the major and minor axis of ellipse may not be parallel to the coordinate axes, which can be viewed as the translation and rotation of the coordinates. As shown in Fig. 3, the xoy axis is translated to $x'o'y'$, and then $x'o'y'$ is rotated to $x''o''y''$. The ellipse in the coordinates $x''o''y''$ is finished. Supposing that the rotation angle is θ, the elliptic equations in the xoy coordinates can be written as

$$\frac{[(x-x_0)\cos\theta+(y_0-b)\sin\theta]^2}{a^2}+\frac{[(x-x_0)\sin\theta+(y_0-b)\cos\theta]^2}{b^2}=1 \tag{2}$$

The expression of the short half axis b is

$$b=\sqrt{\frac{a^2[(x-x_0)\sin\theta-(y_0-b)\cos\theta]^2}{a^2-[(x-x_0)\cos\theta+(y_0-b)\sin\theta]^2}} \tag{3}$$

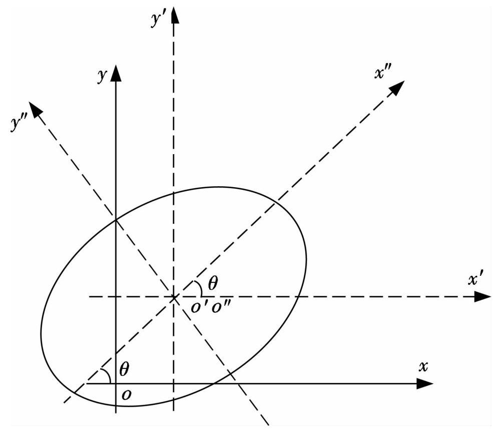

Fig. 3 The schematic of elliptic rotation and translation

Based on contour tracking, each profile in the list is processed in turn. The steps are as follows:

1) For each profile in the list, initialize the horizontal and vertical coordinates of the initial and end points from the neighborhood control structure.

2) Do circulation processing of each pixel point in the current contour neighborhood supposing that the point is the center point C of the ellipse. Calculate the Euclidean distance of every point in the current profile to point C, find the maximum distance value, set it as the semi major axis of the elliptic, and preserve the corresponding point P.

3) If the maximum distance value found in Step 2) is less than the specified threshold, then switch to Step 2) and treat the next pixel of neighborhood structure, otherwise, calculate the angle between point P and C connection and x axis.

4) Do circular processing of every pixel in the current profile. According to Eq. (3), calculate the ellipse semi minor axis b, and plus 1 to the value of each pixel in the accumulator of the semi minor axis.

5) Carry out circular treatment for each element of the accumulator of the semi minor axis. If its value is between the upper and lower bounds of the prescribed threshold, set the current a, b, C, θ, respectively, as the semi major axis, ellipse semi minor axis, center, rotation angle of coordinate value, to obtain all the parameters of elliptic equations, and add them to the list of ellipses.

6) Empty the semi minor axis accumulator array.

If there are any pixels of the current neighborhood profile not disposed of, turn to Step 2), otherwise, turn to Step 7).

7) If there are some outlines left in the list, turn to Step 1), otherwise, the algorithm terminates.

Performing the Hough transform to each scattered contour field and reducing the processing range can improve the processing speed effectively, so the system can satisfy the real-time requirement[12].

2.3 The image matching algorithm

Although the improved Hough transform algorithm can recognize ellipses on the surface of the road, the average case is very complex due to many other interfering elliptic objects; therefore, the manhole cover cannot be distinguished from the elliptical interference. To solve this problem, this paper adopts the color recognition and image alignment algorithm after staining the manhole cover at the same time. Besides the improved Hough method, the comprehensive discrimination method combining these two algorithms can improve the accuracy of the recognition. At the same time, the image matching algorithm can distinguish between suspect broken or missing manhole covers by different rates[13].

For the image matching algorithm, it requires a stored image of the standard pavement of the manhole cover part as a standard reference, and then the image is pretreated. Since the detected pavement image and standard image are different, after pretreatment, a registration of the standard pavement image and the detected pavement image is required. In the process of detecting, compared with the input image and the standard image, if the difference is greater than a certain threshold, the manhole cover is suspected to be broken or missing. As shown in Fig. 4, the image in Fig. 4 is the manhole cover pavement image.

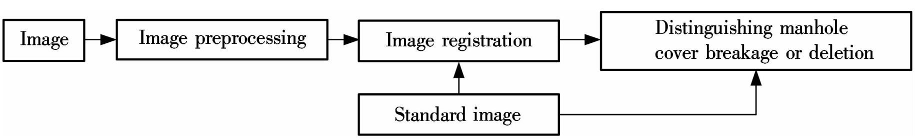

Fig. 4 The process of inspecting manhole cover's breakage and loss

Image registration is a fundamental task in image processing and is used to match two or more images acquired at different time, different sensors, different angles and different shooting conditions[13]. Considering the actual situation of the defective detection system, the difference between the collected detected image and standard image is rigid deformation, so we can use the registration method based on gray level information.

Assume that the standard reference image is R; the detecting image is S, the size of R is $m \times n$, the size of S is $M \times N$, as shown in Fig. 5. The basic process of the image registration method based on gray level information is as follows: superimpose the reference image R on the image S and translate; let the area covered by the reference image on the searching image S to be the subgraph of S_{ij}; (i, j) is the coordinates of the upper left corner of subgraph in the image on the S. The search range is

$$1 \leqslant i \leqslant M - m, \ 1 \leqslant j \leqslant N - n \quad (4)$$

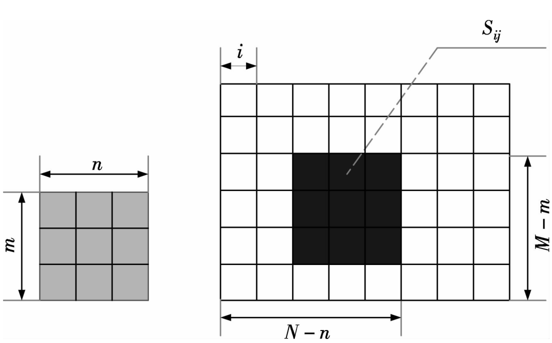

Fig. 5 The basic process of image registration method

The registration process is completed by analyzing the similarity between R and S_{ij}.

According to the similarity measure function, the registration methods based on gray level information can be classified into the cross-correlation algorithm, the maximum mutual information registration method etc. The cross-correlation algorithm is used to realize the registration of two images, which is the most basic image registration method based on gray level statistics. It requires the reference image and the matching image with a similar scale and gray information. The cross-correlation algorithm is used to match the selected region of the image on the reference template and to calculate the cross correlation coefficient for each position on the reference image and the matching image. The choice of the method is due to that before calculating the cross correlation coefficient of the reference image and the test image, a rotating operation is needed to ensure that the maximum cross correlation coefficient is achieved when the axes of two plates are parallel. To maintain an unchanged standard plate direction, we only move the test plate, which can reduce error and improve registration accuracy. The registration process is shown in Fig. 6.

1) According to the preset step value, rotate the measured pavement image within a certain angle range (including the forward rotation and the backward rotation). After each rotation, conduct a cross correlation calculation of the selected area of two pictures.

2) Choose the corresponding rotation angle when the

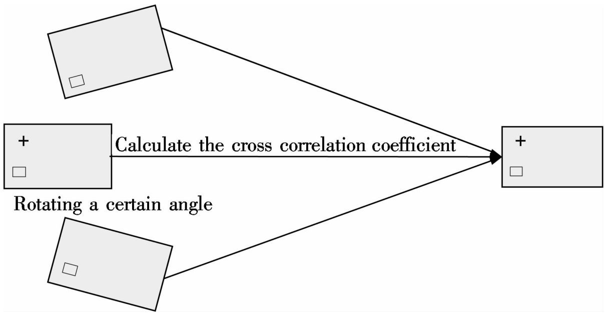

Fig. 6 The process of image registration by cross-correlation algorithm

cross-correlation coefficient reaches the maximum; modify the measured pavement image according to the angle and the axial of two images will become parallel.

3) Select some area on the revised image of the pavement surface, and then calculate the cross-correlation coefficient. This is mainly in order to obtain the corresponding position when the coefficient reaches its maximum.

4) Using the position of the maximum value, we can deduce the relationship between pixel values of the corresponding points on the two images. Through translation and a cutting operation, complete the registration.

Conduct the XOR Boolean calculation after matching the detecting manhole cover image with the standard image of the two values, and then create the outline of image change. After some morphological treatment, we can obtain the suspected damaged area of the manhole cover. We find the manhole cover area through the method of Hough and color recognition and the alarm will sound when the manhole cover area is beyond a certain threshold by calculating the suspected damage zone size in its region.

3 Program Verification

A simulation platform was developed based on the Matlab. The experimental image is obtained by the color video camera. Figs. 7 to 9 show the key steps of image processing. In each of Figs. 7 to 9, the subfigure (a) is the original image of a manhole cover, subfigure (b) is a manhole cover image after dyeing, subfigure (c) is an image of the manhole cover after damage or loss, subfigure (d) is the preprocessed image of a manhole cover after damage or loss, subfigure (e) is an alarming manhole cover image of the suspected defect. Fig. 7 shows a manhole cover with a small area of the damage; Fig. 8 presents a manhole cover with a large area of damage; and Fig. 9 shows the pictures of a completely lost manhole cover. It is seen that this system can accurately sound the alarm for manhole cover damage or loss in the above three situations.

4 Conclusion

In this paper, the edge contour tracking algorithm is first used to find all the edges of broken manhole cover based on the pre-processing image. Then, the improved Hough transform is adopted to find all the elliptic regions

(a) (b) (c) (d) (e)

Fig. 7 The manhole cover with a small area of damage. (a) Original image; (b) Dyed image; (c) Image of damaged cover; (d) Preprocessed image; (e) Alarm of damage

(a) (b) (c) (d) (e)

Fig. 8 The manhole cover with a large area of damage. (a) Original image; (b) Dyed image; (c) Image of damaged cover; (d) Preprocessed image; (e) Alarm of damage

(a) (b) (c) (d) (e)

Fig. 9 The completely lost manhole cover. (a) Original image; (b) Dyed image; (c) Image of damaged cover; (d) Preprocessed image; (e) Alarm of damage and the color recognition algorithm is adopted to distinguish the manhole cover area from the elliptic regions. The proposed synthesis algorithm can not only eliminate the interference from other elliptic objects, but also exclude the interference of other color approximate regions. Therefore, it can accurately determine the manhole cover area. After the manhole cover area is identified, the damage rate can be calculated by the image matching algorithm. Whether the change rate reaches the threshold value can be used to determine whether it is a suspected damaged manhole cover or not. This synthesis algorithm can effectively improve the processing speed of the traditional Hough transform and reduce inefficient sampling accumulation. The experimental results show that the synthesis algorithm has a good early warning effect in complex backgrounds from different perspectives, and in different videoing time and conditions, such as when the target is partially covered.

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基于改进 Hough 与图像比对法的窨井盖疑似破裂检测

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摘要: 由于不能及时发现城市道路窨井盖的破损和缺失,对市民的生命与财产安全造成极大的伤害,且目前已见报道的诸多研究成果均存在实施难度的问题,基于城市道路现有的道路视频图像,提出了针对复杂路面情况下识别窨井盖破损和缺失的改进 Hough 变换与图像比对综合算法. 在经过预处理的图像上,利用边缘跟踪算法找到所有的边缘轮廓后,利用改进的 Hough 变换、色彩识别与图像比对算法找到窨井盖区域,同时计算出窨井盖区域变化率,根据变化率是否达到阈值来判别窨井盖是否有疑似破损与缺失情况. 该方案有效地提高了传统 Hough 变换的处理速度,减少了无效采样、累积. 实验结果表明,该算法在多种复杂背景、不同视角、不同拍摄时间和条件、目标被部分遮挡等情况下都有很好的定位与缺失预警效果.

关键词: 窨井盖;边缘跟踪;改进 Hough 变换;形状检测;图像比对

中图分类号: TP391