Research on and Application of the Control of Manhole Cover in the Launching Silo Based on Machine Vision Technology

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Abstract. The manhole cover is an important part of the launching device as a whole because its uncovering state is vital to the whole switching process. The contact switch is now mainly used to judge whether the manhole cover is in place; however, in this way, the state of the manhole cover cannot be directly observed. In order to improve this aspect, this paper adopts machine vision technology to detect the state of the manhole cover and observe the switching process of the manhole cover and detect the in-position signal in real-time by setting a target at a specific position and identifying the target signal using digital image processing technology. Experiment shows that machine vision technology can quickly identify the target signal and directly observe the switching process of the manhole cover.

1. Introduction

The manhole cover plays a vital role in the guided missile launcher [1], because its uncovering state determines the normal operation of the entire task. Today, the contact switches at different positions using an open-loop control system are used to judge the position and state of the manhole cover, which is low in control precision and poor in repeatability of the manhole cover switching process. The error in the opening position of the manhole cover sometimes seriously hinders the rapid and accurate response of the entire missile launching system [2]. Therefore, improving the control accuracy is crucial to the operation of the cover switching system. By setting corresponding targets at different positions of the manhole cover and obtaining its accurate position and state in real time through machine vision technology, the control precision of the manhole movement is effectively improved.

2. Movement analysis of manhole cover

The structure of a typical silo cover [3] is shown in Figure 1. In the traditional control system, the electronic control device is responsible for adjusting the oil pressure in the hydraulic cylinder by controlling the proportional speed control valve, thus controlling the cover opening process; on receiving the contact switch signal, the cover is judged to be in place. The machine vision technology is to use a camera to continuously observe the moving state during its opening and cyclically detect the target signal by installing corresponding target signals on the linkage mechanical structure during the rotation of the manhole cover. After receiving the video signal, the electronic control device processes each captured image to directly judge whether the cover is stuck during opening through the
liquid crystal display; when the target signal is detected, it quickly identifies the target and displays the in-position signals, during which the most critical part is the detection of the target signal.

The detection algorithm of the target signal includes target image pre-processing and shape recognition of the target image. The former means to extract the contour information in the target image using edge filtering, edge extraction and other algorithms, while the latter means to calculate the length and width and the angle of the target image by calibration, and compare them with those in the ideal situation in order to determine the in-place state of the manhole cover.

3. Target detection

3.1. Distortion correction

Image distortion, as is a typical barrel distortion, is caused by the wide-angle lens. The distortion is small in the center of the image, but gets bigger away from the center, as shown in Figure 2.

Therefore, it is necessary to first perform distortion correction on the target image acquired by the camera. This paper adopts the calibration method proposed by Zhang Zhengyou to obtain the distortion correction parameters of the image acquisition system. For the basic principle, see Equation (1).

\[
s \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = K \begin{bmatrix} r_1 & r_2 & r_3 & t \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} r_1 & r_2 & t \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix}
\]

- S—any scale factor
- \([u \ v \ 1]^T\)—the homogeneous coordinate of the point on the calibration template imaged to the point on the image plane
K—the internal parameter matrix of the camera

\( t, [r_1 \ r_2 \ r_3] \)—the translation vector and rotation matrix of the camera coordinate system relative to the world coordinate system

\([X \ Y \ 1]^T\)—The homogeneous coordinates of the points on the calibration template

Since only the contour information of the target is acquired during the recognition process, it can be assumed that the plane of the calibration template is the \( Z = 0 \) plane of the world coordinate system. Specifically, it means to collect the checkerboard images of different positions in the camera field, calculate the distortion correction parameters of the system based on the feature points in the image, and perform distortion correction on the target image \( P \), as shown in Formula (2). The comparison picture before and after correction is shown in Figure 3.

\[
F = \begin{bmatrix} r_1 & r_2 & t \end{bmatrix} * P
\]

(F is the target image after distortion correction.)

Figure 3. Contrast image before and after distortion correction

3.2. Contour extraction

In order to minimize the influence of noise in the target image on the target edge detection result, it is necessary to filter out noise in the target image \( F \) after distortion correction to prevent false detection caused by noisy dots. The Gaussian smoothing filter can smooth the image so as to reduce the effect of noise points on the edge detector. Its kernel size is chosen to be \((2k+1) \times (2k+1)\), which can be generated by Equation (3).

\[
H_{i,j} = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{(i - (k + l))^2}{2\sigma^2} + \frac{(j - (k + l))^2}{2\sigma^2}\right)
\]

In this equation, \( l \leq I \) (I is the width of the target image), \( j \leq (2k + 1) \) (k is an integer). In the test, \( \sigma = 1.4 \), and the Gaussian convolution kernel is:

\[
H = \begin{bmatrix}
0.0924 & 0.1192 & 0.0924 \\
0.1192 & 0.1538 & 0.1192 \\
0.0924 & 0.1192 & 0.0924 \\
\end{bmatrix}
\]

Perform the convolution operation on the pixel points of the target image \( F \) after distortion correction using the Gaussian convolution kernel (each operation is for a 3\times3 adjacent pixel), thus obtaining the filtered image \( G \), then:

\[
g_{i,j} = H * f_{i,j}
\]
\( f_{i,j} \) represents the gray value of pixel in the i-th row and the j-th column in the target image after the distortion correction; \( g_{i,j} \) represents the gray value of the pixel in the i-th row and the j-th column of the image after the Gaussian filtering.

Then, calculate the gradient strength \( A \) and the direction \( \Phi \) of the filtered image \( G \) using the Sobel operator, wherein the horizontal \( S_x \) and vertical operators \( S_y \) of the Sobel operator are as follows:

\[
S_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad S_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}
\]

\( S_x \) detects the edge of the horizontal direction of the image, while \( S_y \) detects that of the vertical direction. The two operators perform convolution operations on the image \( G \), respectively, thus obtaining a horizontal image \( H \) and a vertical image \( V \), as shown in Equations (5) and (6).

\[
h_{i,j} = S_x \ast g_{i,j} \quad (5)
\]

\[
v_{i,j} = S_y \ast g_{i,j} \quad (6)
\]

\( h_{i,j} \) is the gray value of the pixel points in the i-th row and the j-th column of the horizontal image \( H \); \( v_{i,j} \) indicates the gray value of the pixel points of the i-th row and the j-th column of the vertical image \( V \). Then calculate the gradient strength and direction of each pixel in the image:

\[
a_{i,j} = \sqrt{h_{i,j}^2 + v_{i,j}^2} \quad (7)
\]

\[
\varphi_{i,j} = \arctan \left( \frac{v_{i,j}}{h_{i,j}} \right) \quad (8)
\]

Due to the fact that the extracted target edges are blurred after gradient calculation, the exact response of the target image should be one and only one. Therefore, a non-maximum suppression algorithm is needed to minimize the gradient values apart from the local maximum to zero. If the gradient intensity of the current pixel is greater than that of the other two adjacent pixels, identify it as an edge point with its gray value of 255 and that of its two adjacent pixels minimized to zero.

3.3. Shape recognition

Calibrated the plane of the target by setting 50 mm X 50 mm white squares, as shown in Figure 4. The contour information of the white squares is extracted using the above method, thus obtaining the correspondence between the actual length of the white square and the pixel value, thereby calculating the actual size of the single pixel. Extract the peripheral contour information of the target image using the above method, and complete the straight line fitting using the least square method; in this way, the length of each side of the target image can be calculated by combining the parameters of the single pixel obtained from calibration. Then, calculate the angle between each line and its intersecting line based on the gradient value of each straight line.
When the actual parameters of the target is consistent with those collected by the camera, identify it as in-place and give the in-position signal.

4. Experiment and analysis
This experiment adopts the Imaging Source DFK 23GP031 industrial camera and Computar industrial lens with a focal length of 12 mm for image acquisition; it adopts CLA1B-WKW LED light source of OSRAM company as the light source and conducts the machine recognition algorithm on Windows Visual Studio 2008. The camera is first used to collect several checkerboard images to obtain the parameters of distortion correction, as shown in Figure 5; then the 10mm*10mm white square is used as the target image, as shown in Figure 6. The target image is corrected by using the acquired distortion correction matrix, and then filtered using the Gaussian filter. The target contour information is acquired using a Sobel operator and the non-maximum suppression algorithm. Finally, fit the linear equation of the target image contour using the least square method; calculate the linear length of the outline of the target image and the angle between the intersecting straight lines based on the parameters obtained by calibration.
Calculate the target length and gradient based on the parameters obtained by calibration, and obtain the angle of the target contour based on the gradient, as shown in Table 1.

Table 1. Target contour calculation data

| Side length (mm) | Angle(°) |
|------------------|----------|
|                  | Actual value | Detected value | Actual value | Detected value |
| 1                | 10        | 9.97            | 90          | 89.95           |
| 2                | 10        | 10.03           | 90          | 89.89           |
| 3                | 10        | 10.02           | 90          | 90.03           |
| 4                | 10        | 9.98            | 90          | 90.02           |
| 5                | 10        | 9.98            | 90          | 90.06           |
| 6                | 10        | 10.01           | 90          | 89.97           |
| 7                | 10        | 10.02           | 90          | 90.02           |
| 8                | 10        | 9.97            | 90          | 89.95           |
| 9                | 10        | 10.98           | 90          | 90.02           |
| 10               | 10        | 10.01           | 90          | 90.04           |

Calculation shows that the information of the identified target contour is consistent with that of the actual target image, that is, a cross cursor is displayed on the target image, indicating that the in-position signal is sent, as shown in Figure 7.
5. Conclusion
It can be seen from the result that the machine vision technology can extract the target contour information and give the in-position signal more quickly than the contact switch. Therefore, setting the target at the specific position of the manhole cover is conducive to the direct observation of the switching process of the manhole cover and the rapid identification of the in-position signal.

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