An Online Tracking Algorithm for Aluminum-Profiles based on Multi-objective Motion Estimation

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Abstract: The key to solve the online counting of aluminum-profiles is how to achieve the tracking of multi-target which run at high speed. In this paper, machine vision technology is used to solve the online tracking problem. Firstly, the connected domain labeling algorithm is used to extract the surface adhesion objects one by one. By using this algorithm, the tracking of aluminum-profiles can be reduced to the tracking of center of mass of the suborbicular area. Secondly, the motive distance of the center of mass is estimated by the correlation analysis of binary projection curve. Finally, the coordinates and displacement of the center of mass are used as the characteristic parameters to achieve accurate location and fast tracking of multi-target. Through the on-line counting test on aluminum-profiles with specifications of 20mm and above, the results show that this algorithm can ensure the count accuracy and real-time.

1. Introduction

The production process of aluminum-profile generally includes casting, extrusion, aging, coloring, fixed length cutting and fixed number packaging. Before packaging, aluminum-profile should be counted first. At present, machine vision technology is often used to solve automatic counting problems in complex. How to track multi-target objects at high speed becomes the key to realize the on-line counting by the machine vision technology.

Although there is very little research on the online automatic counting of aluminum-profiles, the research of the online counting of rebar has been carried out in some universities and enterprises. In 2014, Xue [1] proposed to use a connected component and a two-dimensional extremum template to identify the bar and then by using geometric features to achieve the matching of bar. In 2019, Li [2] proposed an improved watershed algorithm to identify the bar contour quickly, and then realized the matching and tracking of the bar based on the displacement of the central point of the contour. In 2006, Zhang et al. [3] realized the extraction of bar centroid by watershed segmentation and center point clustering algorithm, and used Kalman filter algorithm to track the multi-bar target. In 2015, Kong [4] extracted the tracking target by means of edge detection, central agglomeration, cluster recognition, etc., and achieves target tracking with the horizontal displacement of the bar as the characteristic variable. In 2012, Peng [5] used the fusion method of Hough transform and near-circular target recognition to realize the extraction of bar center, and then realized the point-to-point tracking of bar by using Kalman motion prediction and small-window search. In 2006, Luoet al [6] proposed to use the grayscale projection curve to calculate the overall displacement of adjacent images to achieve the initial alignment, and then calculated the integral value of the grayscale projection of all the initial alignment objects. Finally, the accurate displacement of each bar is obtained by the weighted average method. By above methods, the counting problem of bar with crossover, stacking and adhesion in the end faces can be solved, but the counting precision still needs to be improved. This is mainly caused by the severe adhesion of the bar end face in the image. And it is difficult to achieve accurate segmentation of the counting object.

Thanks for some similarities in the online counting between aluminum-profiles and bars, they can learn from each other. Through the analysis of the above methods, we can easily find that the multi-target tracking problem can be solved from the two aspects, which are the target recognition and the target matching. This paper proposes an algorithm for accurately extracting tracking objects by the suborbicular connected region (SCR) marking method. Then, we use centroid coordinates of the SCR as the characteristic parameters to track the targets. In this way, the tracking problem of multi-object predigests into the centroid tracking problem of the SCR, which greatly reduces the algorithm's time. In this paper, the overall displacement of the aluminum-profile is obtained by correlation analysis of the binary projection curve under the circumstances of ignoring the jitter and vibration of the conveyor. The overall displacement is used as an estimate value for each aluminum-profile. Then it is combined with threshold judgment to solve the matching problem of aluminum-profiles in adjacent frame images. Finally, to achieve accurately tracking of multiple moving targets.

2. Identification of the Tracking Objects

2.1 Determination of the Tracking Objects

Since the production line moves very fast (nearly to 200mm/s-400mm/s), the system selects a 300,000-pixel CCD industrial camera with global shutter to avoid serious tailing phenomenon [7]. The camera captures 60 frame images per second and computer extracts 1 frame image every 50ms for the counting analysis. After ROI clipping, noise reduction and binarization, the obtained image is shown in Figure 1. In order to reduce the difficulty in subsequent image processing and raise the accuracy of counting, we set the height limit baffle and the alignment baffle in front of the counting area. In this way, the problems of stacking and occluding the end faces of aluminum-profiles can be solved, and also make sure that the aluminum-profiles in the image are aligned and only have one layer.

By looking at Figure 1, it is not difficult to find that there exist one SCR in the center of each aluminum-profile. If these SCRs can be extracted, the complex tracking problem of aluminum-profiles with adhesive end faces can be predigests into independent SCRs tracking.

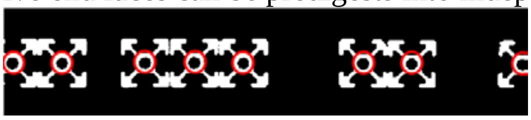

Fig. 1 SCR of the end face of aluminum-profile

2.2 Extraction of Tracked Objects

Since the SCR of each aluminum-profile is continuous and the range for that is large enough, this paper adopts the connected domain marking algorithm to extract the SCR. In order to increase the operation speed, the 4-adjacency method is used to find the connected region with the pixel value of 0.

Fig. 2 Tracked object of 20mm aluminum-profile

As show in Figure 1, the connected regions with the pixel value of 0 not only include the SCR, but also include the background region and the noise region. However, the area of the background area is much larger than that of the SCR, while the area of the noise area is much smaller than that of the SCR. So, the SCR can be identified by the judgment of area size. Then, the SCR is extracted from the image by setting all pixel values of each SCR to 1 and setting all pixel values of other regions to 0. The result is shown in Figure 2. In this system, the area threshold of the 20mm aluminum-profile is 150~170 pixels, 300~330 pixels for 30mm profiles, and 450~480 pixels for 40mm profiles.

2.3 Elimination of Interference Areas

By the judgment of area size, the SCR in the middle of the 20mm aluminum-profile can be extracted accurately. However, with the same method, the SCRs extracted from aluminum-profiles over 30mm include the SCR (Ya) in the middle of aluminum-profiles and the SCR (Yb) at the four corners of aluminum-profiles, as shown in Figure 3. SCR (Yb) is an interference region that will cause trouble for subsequent tracking.

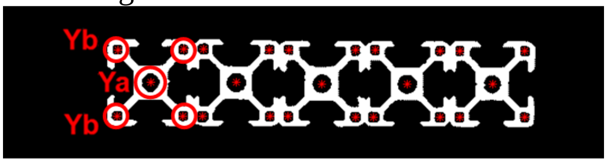

Fig. 3 SCR of 30mm aluminum-profile

It can see from the image that the centers of mass of SCR in the center of aluminum-profile are almost locate on the same horizontal line, which are greater difference in the Y-axis from the centers of mass of the interference areas. Therefore, this paper sets a reference value (Y_{st}) and a threshold value (5) for coordinates. Only if the difference between the Y value of the SCR centroid and Y_{st} is less than the threshold, all pixels of the SCR will be set to 1 as the tracking object. Otherwise, all pixels of the SCR will be set to 0 as the background.

As shown in Figure 2 and Figure 4, there is a corresponding relationship between the number of SCRs and aluminum-profiles after removing the interference regions.

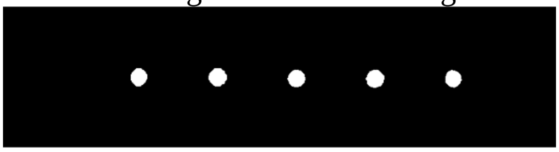

Fig. 4 Tracked object of 30mm aluminum-profile

3. Implementation of Multi-target Tracking

Below are some main problems which should be solved on the online tracking of aluminum-profiles:

(1) How to distinguish aluminum-profiles in or out of the tracking area?

(2) How to distinguish between counted and uncounted aluminum-profiles?

(3) How to determine the counterpoint of each aluminum-profile between adjacent frames?

Mainly common algorithms for target tracking are tracking based on feature parameter matching, tracking based on region, tracking based on contour, and tracking based on 3D model [8]. Because the profile of aluminum-profiles is very similar, and the movement of aluminum-profiles may lead to an incomplete collection for end face (such as the rightmost aluminum-profile in Figure 1), the tracking algorithm based on region and contour is not suitable for tracking aluminum-profiles. Given that real-time performance and accuracy are the two most important technical indicators for online counting of aluminum-profiles, the target tracking algorithm based on characteristic parameter matching is adopted finally.

3.1 Selection of Characteristic Parameters

The area, perimeter, moment, displacement, center of mass coordinates and other parameters of SCR can be used as the characteristic parameters of the target tracking. Aluminum-profiles belongs to rigid objects. If its position changes, its centroid coordinates also move. And the displacement of CMAP (the centers of mass of aluminum-profile) must be equal to the displacement of aluminum-profiles. As mentioned above, the end face of the aluminum-profile in the image may be incomplete, which cause the values of area, circumference, moment and other parameters obtained by image processing technology inconsistent with the actual values of the aluminum-profiles.

Therefore, this paper takes the coordinate and displacement of CMAP as the characteristic parameters for tracking.

3.2 Calculation of Characteristic Parameters

A tiny conveyor jitter during motion will lead to horizontal displacement and vertical displacement of the aluminum-profile. But the vertical displacement is vanishingly small. Not only that, but the sampling period of the image is only 50ms, so the change of the vertical displacement of the same CMAP is negligible in such a short time. It can be considered that only horizontal displacement exists between the adjacent images.

Assuming that the *i*-th CMAP coordinates in the *t*-th image are (X_i, Y_i) (i= 1,2,3…), the *i*-th CMAP coordinates in the (*t*+1)-th image are($\overline{X}_i$, $\overline{Y}_i$), and Δx_i is the horizontal displacement of the *i*-th aluminum-profile between the *t*-th and (*t*+1)-th images. $\overline{X}_i$ and $\overline{Y}_i$ can be calculated by Equation (1).

$$\overline{X}_i = X_i + \Delta x_i \; ; \quad \overline{Y}_i = Y_i \tag{1}$$

Since there is a large number of aluminum-profiles need to be tracked in each image, the real-time performance on the tracking will be bad if calculate the actual displacement for each sample. Given the smoothly running of the conveyor and the sampling interval between adjacent images is very short, we ignore the slight relative displacement that may exist between the aluminum-profile and the conveyor. It is considered that the displacement of all aluminum-profiles is the same. Therefore, in order to improve the real-time performance of the algorithm, all aluminum-profiles in an image are treated as a whole, and the overall horizontal displacement (Δx) is used as the estimated value (Δx_i) of the actual horizontal displacement for each aluminum-profile.

The overall horizontal displacement can be obtained by analyzing the correlation of the vertical projection curves of adjacent images. And the vertical projection curve (P) of the binary image can be calculated by Equation (2), which is used to count the number of pixels with a value as 1 on each column of the image.

$$P(x) = \sum_{y=0}^{y\max} g(x, y) \tag{2}$$

Where g (x, y) is the binary image of the end face of the aluminum-profile, y_{max} is the maximum row value of image g (x, y).

The correlation (H) of the vertical projection curve between adjacent images can be calculated by Equation (3).

$$H(\Delta x) = \sum_{x=0}^{x\max} P_A(x) * P_B(x - \Delta x) \Bigg/ \sum_{x=0}^{x\max} P_A(x) \sum_{x=0}^{x\max} P_B(x - \Delta x) \tag{3}$$

Where $P_A(x)$ and $P_B(x)$ are vertical projection curves of adjacent images, x_{max} is the maximum column value of image g (x, y).

When H reaches the maximum value, it indicates that the correlation of the projection curve between adjacent images is the largest. At this point, the horizontal deviation (Δx) of the two projection curves is the overall horizontal displacement.

3.3 Setting the Tracking Area

The movement speed of the aluminum-profile is about 200mm/s-400mm/s. In order to ensure the accuracy of counting, we set a tracking area with the length of 300mm and the width of 46mm. And $X_{\min}$ is the left boundary of the tracking area, while $X_{\max}$ is the right boundary of the tracking area. Aluminum-profiles will be counted only when they appear more than once time during the tracking area. Since the frame rate of industrial camera is 60 frames /s in this system, and the displacement of aluminum-profile between adjacent images is less than 4mm, capturing an image every 50ms can meet the tracking requirements.

3.4 Target Matching and Tracking

By Equation (1), it can be estimated that the *i*-th CMAP coordinates is $(\bar{X}_I, \bar{Y}_i)$ in the (*t*+1)-th image after 50ms. If $\bar{X}_i - \Delta x < X_{\min}$, it is considered that the *i*-th aluminum-profile has just entered the tracking area at the (*t*+1)-th frame image. And the matching of the *i*-th aluminum-profile will be deferred to the (*t*+2)-th image. If $\bar{X}_i > X_{\max}$, it is considered that the *i*-th aluminum-profile has already left the tracking area and has no need to match in (*t*+1)-th image. Only when $X_{\min} < \bar{X}_i < X_{\max}$, the *i*-th aluminum-profile need match.

It is very difficult to find a matching object between the *t*-th image and the (*t*+1)-th image directly by estimated values $(\bar{X}_i, \bar{Y}_i)$. The reason for this problem is that the slight friction and jitter during the movement of the aluminum-profile are inevitable. So, there is some deviation between the actual displacement and the estimated displacement (Δx) of the aluminum-profile. Besides, illumination angle change, noise interference, etc. will also cause a slight deviation between the displacement in the image and the actual displacement of the aluminum-profile. In order to avoid the matching failure caused by deviation, we introduce the thresholds *a* and *β* in the target matching algorithm, as shown in Equation 4.

$$D = \left\{ (\bar{X}_i, \bar{Y}_i) \middle| X_j - \alpha < \bar{X}_i < X_j + \alpha \,\&\&\, Y_j - \beta < \bar{Y}_i < Y_j + \beta \right\} \tag{4}$$

Where *j* = 1, 2, 3…, *j* is the serial number of the aluminum-profile in the (*t*+1)-th image. (X_j, Y_j) is the actual values of the CMAP coordinate in the (*t*+1)-th image.

In the (*t*+1)-th image, if the difference between the actual value and the estimated value of the CMAP coordinates is less than the threshold, that is, *D*=1, it is considered that the *j*-th aluminum-profile in the (*t*+1)-th image is the *i*-th aluminum-profile in the *t*-th image. If *D*=0, it is considered that the matching between the *j*-th aluminum-profile and the *i*-th aluminum-profile fails in the (*t*+1)-th image. After testing many times, *a* and *β* are selected to be 6 and 3, respectively. The implementation process of aluminum-profile tracking by Equation (4) is shown in Figure 5.

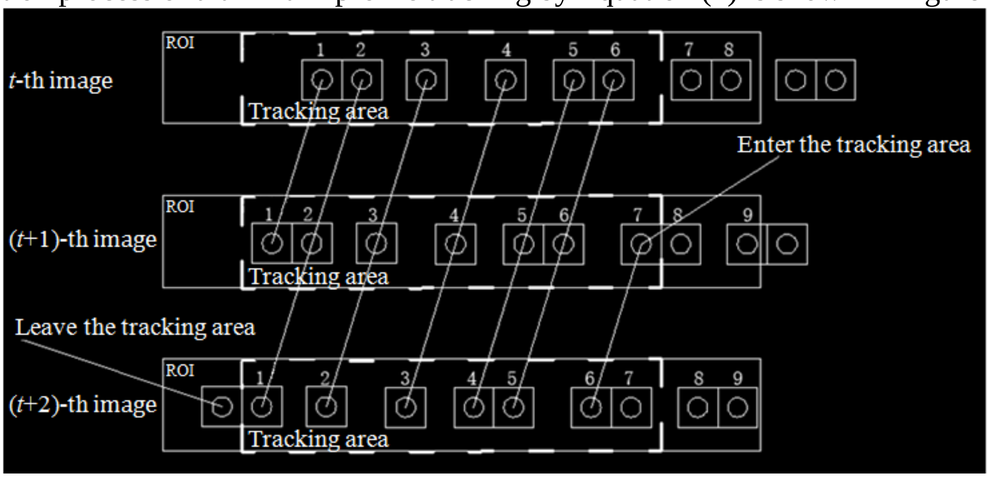

Fig. 5 Target matching and tracking

4. Experimental Result

The purpose of tracking is to ensure that each image of the aluminum-profiles will be counted and no more repeat count will occur during the online counting process. Therefore, we can test the accuracy of the tracking algorithm by the accuracy of aluminum-profiles counting in the sequence images.

4.1 Implementation of Online Counting

If an aluminum-profile just be counted after only one successful match, it may cause some error counts by the problems such as interference. Therefore, in order to ensure the accuracy of counting, the aluminum-profiles should be counted after multiple successful matching [9]. So, how to determine the amount (*K*) of matches successful? When the acquisition cycle is 50ms, each aluminum-profile can be photographed at least 20 times in the tracking area. Therefore, the K could be chosen between 1-20. But if the value is too high, it will reduce the real-time performance of online counting. After several tests, the K is set as 3 in this paper. The online counting process of aluminum-profiles is shown as follows:

Step 1: Calculating the overall horizontal displacement (Δx) between adjacent images by Equation (3).

Step 2: Obtaining and saving all CMAP coordinates in the t-th and (t+1)-th image.

Step 3: Estimating the position of all aluminum-profiles of the t-th image in the (t+1)-th image by Equation (1), and removing the aluminum-profile beyond the tracking area.

Step 4: Finding the matching object in the (t+1)-th image for all aluminum-profiles in the t-th image by Equation (4) in the tracking area. If D_i=1, indicating that the i-th aluminum-profile finds a matching object, let $K_i = K_i + 1$. If D_i =0, indicating that the i-th aluminum-profile does not find a matching object, then K_i remains unchanged.

Step 5: Judging the value of K_i to determine if it needs to be counted. If $K_i = 3$, means that the matching times of the i-th aluminum-profile have meet the counting requirement, but the aluminum-profile has not been counted yet. The total quantity of aluminum-profiles should be N=N+1. If $K_i \neq 3$, it means that the matching times of the i-th aluminum-profile fail to meet the counting requirements or have already been counted, then the total number of aluminum-profiles N remains the same.

Step 6: Saving each CMAP coordinate in (t+1)-th image as the matching basis for the next image.

Step 7: Repeating steps 2-6 to achieve tracking and counting of the aluminum-profile in sequence images.

4.2 Analysis of the Results

In order to test the accuracy of the tracking algorithm, three types of aluminum-profiles with cross-sectional widths of 20mm, 30mm and 40mm were tested. Some experimental results are shown in Table 1. As shown in Table 1, the accuracy of the tracking algorithm in this paper nearly be 100% for the smallest 20 mm aluminum-profiles. Different placement modes of aluminum-profiles (such as separation, adhesion, tilt, crossover, etc.) occur in each test. The testing results show that the tracking algorithm is insensitive to the placement modes and could effectively avoid error count.

Table 1. Experimental results of online counting

Specification	Actual value(root)	Counting value (root)	Accuracy	Processing time/frame (s)
20mm	80	79	98.75%	0.045
	80	80	100%	0.044
	80	80	100%	0.046
	80	80	100%	0.041
	80	78	97.50%	0.045
30mm	80	79	98.75%	0.042
	80	80	100%	0.044
	80	80	100%	0.041
	80	80	100%	0.043
	80	80	100%	0.042
40mm	80	80	100%	0.042
	80	80	100%	0.042
	80	80	100%	0.039
	80	80	100%	0.041
	80	80	100%	0.043

It has been observed that the error count generally occurs when the cross-section of the aluminum-profile is serious distortion which is mainly caused by irregular shearing. But this is an extremely rare occurrence. The severely distorted cross- section makes the SCR in the center of the end image of the aluminum-profile fail to identify.

5. Conclusion

In this paper, the machine vision technology is used to solve the moving multi-target objects tracking in the aluminum-profile online counting system. We consider the centroid coordinates and displacement of aluminum-profiles as characteristic parameters, and combine connected domain marking algorithm, motion prediction method and fault tolerant algorithm to realize an accurate and fast tracking of the multi objects. This algorithm can well solve the problems of hard to be tracked which caused by the aluminum-profile fast motion and hard to be recognized because of end adhesion in the images. The algorithm's counting accuracy for aluminum-profiles with a minimum specification of 20mm is nearly to 100%. It can effectively avoid false tracking and false counting. However, the accuracy of the tracking algorithm for aluminum-profiles with severe cross-section deformation still needs to be improved.

Acknowledgements

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