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Detection and Tracking Algorithm of the Calibration Line and the Groove Line based on vision

Li Sha sha
College of Automation, Harbin Engineering University, Harbin, Heilongjiang 150001, China

Abstract: A new detection and tracking algorithm of the calibration line and the groove line for automatic calibration cutting system was advanced. The algorithm utilizes the generalized curve parameter model, which can describe both straight and curved line. The most prominent contribution of the detection algorithm lies in that: both the Adaptive Random Hough Transformation (ARHT) algorithm and the Tabu search algorithm are used to calculate the different parameters in the model according to different demands of accuracy for different parameters. Furthermore, a multi-resolution strategy is proposed to reduce the time-consumption of the whole system. At last, this paper also presents a tracking algorithm based on the particle filter to improve the stability of the whole system. Extensive experiments in variable occasions are implemented to prove the approach to be both robust and fast, besides, the algorithms can extract the calibration line and the groove line accurately even under unsatisfactory illumination situations.

Key words: Detection algorithm, ARHT, Tabu search, particle filter, tracking algorithm

INTRODUCTION

In Industrial production, the people conduct relevant research about visual tracking system based on the cutting path of robot. There are many benefits, if camera is used for automatic follow cutting. It is validated that the scheme has high efficiency and low charge, and it can supervise dynamic process on line (Shen *et al*., 2007; He *et al*., 2000; Shi *et al*., 2009; Chen, 2007).

A new detection and tracking algorithm of the calibration line and the groove line for automatic calibration cutting system was advanced. The calibration line and the groove line can be drawn quickly and accurately. The algorithms take advantage of generalized curve lane parameter model, which can describe both straight and curved lanes. Moreover, image edge extraction can achieve image edge amplitude and image edge direction. The most prominent contribution of the detection algorithm lies in that: both the Adaptive Random Hough Transformation (ARHT) algorithm and the Tabu search algorithm are used to calculate the different parameters in the calibration line and the groove line model according to different demands of accuracy for different parameters. In the all calculation process, a multi-resolution strategy is introduced. Parameters modules are solved from 1/4 image to 1/2 image to the original image respectively. Therefore, the precision of the parameters is escalated. At last, this paper also presents a tracking algorithm based on the particle filter to improve the stability of the whole system.

The parameter model of calibration line and groove line: Cutting track will be engraved on the steel plate in advance, before cutting. In order to ensure the cutting precision, a calibration line will be needed. The calibration line and cutting track are parallel. The cutting track of robot will be corrected according to the parallel relation of the calibration line and cutting track in real time (Shen *et al*., 2008).

The vision sensor is installed on the robot, which is always perpendicular to the steel plate. In the all process of cutting, the relative height of vision sensor and steel plate did not change. Moreover, check line and groove line at the same level, which is a parallel with the level. Therefore, according to the perspective transformation theory of camera, the calibration line and the groove line can be denoted by the curve of the horizontal plane (Kreucher and Lakshmanan, 1999; Chen, 2007).

The parameter model of curve: The arc of level can transform the curve of the level. Therefore, the calibration line and the groove line can be expressed as formula (1):

$$x = c / (y - h_z) + S_\Delta (y - h_z) + t_d \tag{1}$$

where, x, y are the horizontal and vertical directions variable respectively. h_Z is hidden line parameters. c is linear ratio of the curve curvature in the horizontal plane. t_d is the curve in the horizontal plane, which is the tangent value of the tangent direction. S_Δ is the offset of the curve relative to the camera in the horizontal plane. Because the left line and the right line have the same tangent direction, the two lines have the same c and t_d. However the S_Δ value of the two lines is different. We can assume that l_1 is the left line and l_2 is the right line, moreover, $l_1 < 0$, $l_2 > 0$.

This study introduced the parameter model of check line and groove line as formulate (1). There will be universal significance that the hyperbola model is introduced. This model suffices cutting detection of the straight line and curve. Formulate (1) expresses a straight line when the c is 0.

THE ANALYSIS OF DETECTION ALGORITHM

Image pre-processing: In order to obtain the edge information of image, the gradient of the input image $f(x, y)$ can be calculated by the Sobel operator with low threshold. Therefore, we can obtain two images; One is gray-scale edge amplitude image $f_m(x, y)$, which is the direction amplitude value of input image and the other is gray-scale edge direction image $f_g(x, y)$, which is the amplitude ratio of vertical gradient and horizontal gradient from the input image:

$$f_x(x,y) = \{f(x+1,y-1) + 2f(x+1,y) + f(x+1,y+1)\} - \{f(x-1,y-1) + 2f(x,y-1) + f(x-1,y+1)\} \quad (2)$$

$$f_x(x,y) = \{f(x-1,y+1) + 2f(x,y+1) + f(x+1,y+1)\} - \{f(x-1,y-1) + 2f(x,y-1) + f(x+1,y-1)\} \quad (3)$$

$$f_m(x,y) = \sqrt{\left(f_x(x,y)\right)^2 + \left(f_y(x,y)\right)^2} \approx \left|f_x(x,y)\right| + \left|f_y(x,y)\right| \quad (4)$$

$$f_g(x,y) = f_y(x,y) / f_x(x,y) \quad (5)$$

The algorithm of adaptive random Hough transformation: The method of Hough transform is very common (Li *et al*., 2010; Lucas *et al*., 2008; Qu Wen Tai *et al*., 2005). It can be used in various edge detections. The algorithm of adaptive random Hough transformation is utilized in this study, which is utilized to calculate the value of parameter curvature c and tangent direction t_d in the model of check line and groove line. This method possesses both advantages of Hough transform and random Hough transformation.

According to the deduction, a pair of pixels $p_1(x_1, y_1)$ and $p_2(x_2, y_2)$ were extracted by random sampling from the gray-scale edge image. The two points lie in the calibration line and the groove line possibility when the gray-scale direction value of p_1 and p_2 satisfy the formulate: $|arctan(g_1) - arctan(g_2)| < thr$. So we can obtain the value of parameter curvature c and tangent direction t_d as follows:

$$c = \frac{(x_1, x_2) + f_g(x_1, x_1)(y_1, h_z) - f_g(x_2, y_2)(y_2, h_z)}{2\left(1/(y_1, h_z) - 1(y_2, h_z)\right)} \quad (6)$$

$$t_d = x_1 - 2c/(y_1 - h_z) + f_g(x_1, y_1)(x_1, h_z) \quad (7)$$

After taking large random sample, we have to select a group of the most probable parameter in the large sampling points, which is the result of the adaptive random Hough transformation. It is necessary that we have to establish a two-dimensional coordinate system. The parameter c is taken as abscissa and the parameter t_d is taken as ordinate respectively in this coordinate system. The calculation result of the parameter corresponds to a point in the coordinate system. There will be a large number of points when the adaptive random Hough transformation completes one iterative. Therefore, we can find a center of circle, and the radius of circle fills needs of the error. If the circle has accommodated as much points in the coordinate system as possible, the coordinate of centre is the final parameters results of this adaptive random Hough transformation.

This study utilizes the maximum a posteriori-based Tabu Search (TS) algorithm to calculate the value of parameter o. The TS algorithm is an interactive and globally optimal searching method (Wang *et al*., 2004). From the beginning, the s could be calculated. According the moving rule which is defined in advance, a neighbourhood s will be produced. We have to calculate the value of the optimization objective function for the every solution of s , and select the best s as the current solution even if the solution is worse than s. Therefore, local optimum of objective function can be restrained. In what follows, a new iterative will be performed: the new current points was calculated from the beginning, the previous process will be repeated until the stop condition is satisfied. This arithmetic may enter infinite loop if a point which has been access becomes neighborhood point once again. In order to avoid this situation, we have to establish a list, also called as “Tabu list”. The m current points are stored in a list. The current point will be passed if its neighborhood points belong to the list.

The selection objective function is maximum a posteriori probability estimation (MAP). Probability of the curve shape in the observation image can be determined by the parameter vector $x = [c, o_1, o_2, t_d]^T$, which is expressed with a likelihood probability density function $p(x|z)$. Therefore, the MAP as follows:

$$x^* = \arg\max p(x|z) \quad (8)$$

Using the Bayes probabilistic theory, we can obtain as follows:

$$x^* = \arg\max p(z|x)p(x) \quad (9)$$

In the cutting process, the groove line is a parallel with the calibration line under ideal conditions. The distance between the groove line and the calibration line is unchanging, so a prior probability density function can be established with the above mentioned model of lines. We can obtain the prior knowledge with above mentioned parameter as given by:

$$x^{*}\arg\max\exp\left(-\frac{(o_2-o_1-\mu)^2}{\sigma^2}\right).\sum_{(x,y)}\left(\begin{pmatrix} f_m(x,y)S(MD_L(x,y)).\left|\cos\theta_L\right|+\\ f_m(x,y)S(MD_R(x,y)).\left|\cos\theta_R\right|\end{pmatrix}\right) \quad (10)$$

where, MD_L (x, y) and MD_R (x, y) express the shortest distance of point (x, y) to the left and right lines. In order to improve the real-time algorithm, the following approximation should be adopted when we calculate MD_L (x, y) and MD_R (x, y) : first, we find a point (x^t, y^t) , which is the intersection of curve and a horizontal line crosses the point (x, y) , and then, calculate the distance of the point (x, y) to the tangent. The approximate error can be omitted when the curvature of the calibration line and the groove line have small changes. Grads direction of point (x, y) and the tangent direction of left line lie at an angle θ_L and grads direction of point (x, y) and the tangent direction of right line lie at an angle θ_R . $S(D)$ is a scoring function, with which the weight coefficient of distance can be measured. S(0) = 1, $S(D)$, monotonic decline from 0 to R along with D, and when $D \geq R$, $S(D) = 1$, $S(D)$, is given by:

$$S(D)=\begin{cases} e^{-D^2/10} & 0\leq D\leq R \\ 0 & other \end{cases} \quad (12)$$

Here, we use the method of random generation to produce neighborhood, the jth neighborhood of the ith component in the parameter vector x is give as:

$$\left\{y \middle| y_j = x_i + R_j W_i S_b\right\} \quad (13)$$

where, R_j is a random number between $[-1,1]$, is the jth component numerical range of the parameter vector x. S_b is a variable step-size parameter.

The Tabu search will be stopped when the iteration times are larger than present value N, besides, the below inequalities is satisfied:

$$\left|x_k^* - x_{k-1}^*\right| \leq \varepsilon \qquad n = 1,\ldots,N$$

Fig. 1 shows the flow chart of Tabu search.

The solution procedure of lines parameter: The solution procedure of each parameter can be seen in Fig. 2. The left part of flow chart adopts ARHT method to calculate the value of parameter c and parameter t_d : in the preprocessed gray edge image, it randomly sampled with gray amplitude value of each pixel weighting, when the sampling points attain a certain number, The above mentioned "search the biggest circle method" was used to find finally result of a ARHT iteration.

After ascertaining the value of parameter c and parameter t_d , the right part of flow chart adopts Tabu

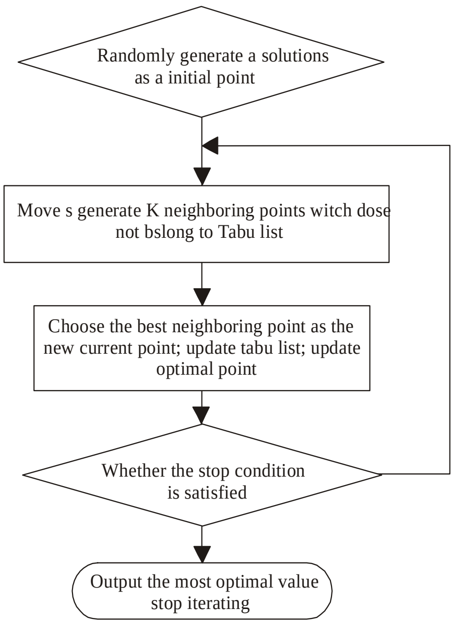

Fig. 1: The flow chart of Tabu search

search to calculate the value of parameter l_1 and parameter l_2: to determine the original limits of the parameter, MAP is the objective function within the range, the optimization parameter will be obtained with iteration.

Multi-resolution strategy: This paper uses multi-resolution strategy for improving the precision and the real-time demand of system. The implementation process as follow: first, the size of original image reduces to $1/2^a$ with cubic interpolation. $a = 1, 2$. The reduced images are called 1/2 image and 1/4 image, respectively. The each parameter of line model can be calculated roughly as Fig. 1 shown. Then, in the 1/2 image, above mentioned flow is repeated, moreover, the value range of and can be reduced reasonably and the step size of Tabu research also can be selected more accurately. At last, in the original image, the final parameter of line will be obtained by the more precise step size and smaller searching area (Isard and Blake, 1998; Rafer *et al*., 2002). The method of "from rough to precise" lets the result of optimization be more precise and effective, besides, improves the speed of checking.

The tracking algorithm: The tracking algorithm of the calibration line and the groove line can improve the speed of checking. Moreover, increase the precision of checking at the same time. In order to reduce the interference from various factors, this paper uses the tracking algorithm based on the particle filter. So called particle, the scale of filter is minimal which express a point in the target state. The so-called filtering is used to filter the current state of target, which also express that current state of target can be estimated with the current and prevenient observations

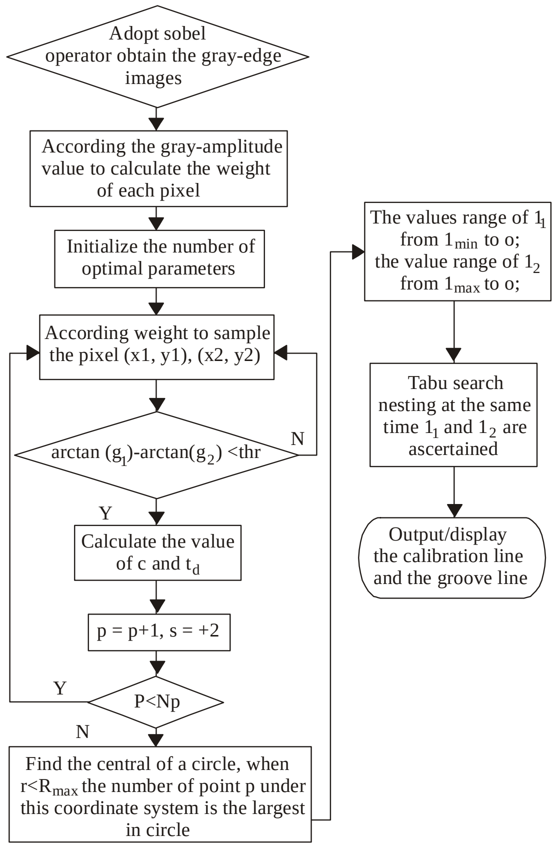

Fig. 2: The flow chart of solving parameters

in the estimation Theory. The method of the particle filter is very agile and practical.

Bayes theorem is the algorithmic base of the particle filter, which takes the parameter s as a random variable. In the absence of new observational data, we are able to attempt a judgment with the experience, in the other words, prior distribution *p* (*s*) will be just used. On the other hand, if we get new observational dates, according to the Bayes theorem, the prior distribution combine with the practical observational data, the posterior probability will be obtained. This paper utilizes state vector $s(t) = [\ (t)\ , w\ (t), u(t), t_d(t)]$, w is the width of the calibration line and the groove line, u is horizontal distance from the camera to the right line.

State space model is a representation method of time series, which is a dynamic time-domain model and takes the implicit time as the independent variable. The state space model includes two parts: the equation of state model, it reflects that the dynamic system transferred to the state under the input variables at a time; the equation of output or observation model, it put the output of system and the state of system and the input variables together.

Visual calibration system of cutting robot only takes camera as single sensor, so the deflection angle and other parameters can't be obtained. This study adopts simple dynamic system model as the equation of state model:

$$\begin{cases} c = c\ (t-1) + r\ (1) \\ w(t) = w\ (t-1) + r\ (2) \\ u(t) = u\ (t-1) + v.\Delta t.\dfrac{1}{t_d(t)} + r\ (3) \\ t_d(t) = t_d\ \ (t-1) + r\ (4) \end{cases} \tag{14}$$

v is the movement speed of the camera horizontally, which along the steel plate. t is the moment of the current frame. The vector $r = [r(1), r(2), r(3), r(4)]$ is a random vector, which used to describe interference environment. Δt is the time difference between the consecutive two frames. The formula (14) show that the curvature parameter of the calibration line and the groove line, tangent direction parameter and the width of the two lines change is very small, but the parameter is update with the cutting process in real time.

When the system state is given, the various parameters of model can be calculated as:

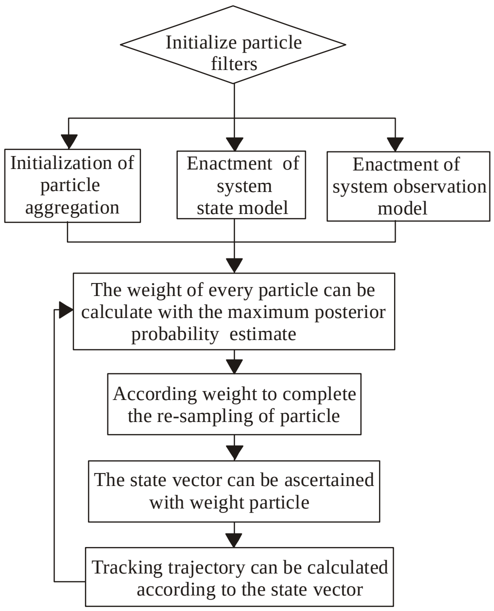

Fig. 3: Flow chart of trajectory tracking algorithm with particle filter

$$\begin{cases} c = c(t) \\ o_1 = -\alpha_u.(w(t) - u(t)) / \alpha_v H \\ o_2 = -\alpha_u.u(t) / \alpha_v H \\ t_d = t_d(t) \end{cases} \tag{15}$$

α_u, α_v denotes the horizontal and vertical scale factors of camera, respectively. H is the height of camera, which need to validate with the observation value (at time t) after giving the spread of target state, also called system observation. Used the observation value is the maximum posterior probability estimate above mentioned, as formula (11):

The checking result of the calibration line and the groove line can be used to initialize particle collection of tracking algorithm. Initial particle comes from a normal distribution. The mean of the normal distribution determine by the state, which is obtained from the detection algorithm. Figure 3 is the iteration flow chart of tracking with particle filter. First, initialize particle filters, include: Initialization of particle aggregation, enactment of system state model and enactment of system observation model; secondly, we have to dope out the initial position of particle through the sampling, the important weighs of every particle can be calculated with the distributing of observation and normalized; and then, the maximum posterior probability estimate is taken as weights to complete the re-sampling of particle; finally, parameter vector of the calibration line and the groove line will be calculated according to the formula (14), return to the second step, perform the whole tracking process.

THE EXPERIMENTAL RESULTS

The checking result of the calibration line and the groove line: The Fig. 4 show that the checking result of lineal checking line with the above mentioned checking arithmetic before cutting. We can see from the Fig. 4, there are serious rust, nick and strong light jamming on the steel plate, however, the algorithm is still very accurately extract the corresponding lines.

The tracking result of calibration line and groove line: In this paper, vision system is installed on the MPCR-5D6000-II curved panel cutting robot, which is our group successfully developed and has been used in the ellipsoidal head board cutting of AP1000 Nuclear Power Station safety shell (CV).

The tracking arithmetic of the calibration line and the groove line are advanced in the study. Owing to the real-time check during the cutting process of steel plate, the system must have good adaptability to the different cutting environment, which has a good robust in detection under a variety of interference conditions. The experimental results of check the calibration line and the groove line in the actual cutting process as Fig. 5 shown. The specific experimental conditions: camera is WTA-902B; camera head is Computer M1618-MP; taking into account the strong light and flame splash cause interference to the visual measurement, the filter and protection lens must be installed in the front of camera head; the filter is narrow-band 650 nm, bandwidth 10 nm and peak transmission of 80%; the vertical distance from lens to steel plate is 260 mm; the horizontal distance from lens to cutting gun is 310 mm; the groove angle is 30º; the speed of cutting is 200 mm/min; every 29 ns capture an image.

The specific experimental result can be seen in the Fig. 5, in the near flame side, the groove line seriously hide behind the flame during cutting. Owing to the strong light interference by cutting, the most of groove line is hided. We choose several frames from the test, which change is very smaller. In the tracking mechanism of the particle filter, it is easy to see from the result of tracking that the extraction result of groove line is tending towards stability. The experimental results show that tracking performance is very obvious when the change of states is less intense, and the system is also very stable.

As the Fig. 5 shown, in the near flame side, the groove line is absent in the images of the 1th frame and the 102th frame. So there is a certain extent deviation during the detection checking process of the groove line. However, in the following tracking, more accurate results is obtained gradually, which thanks to the update mechanism of the particle filter. The experimental results

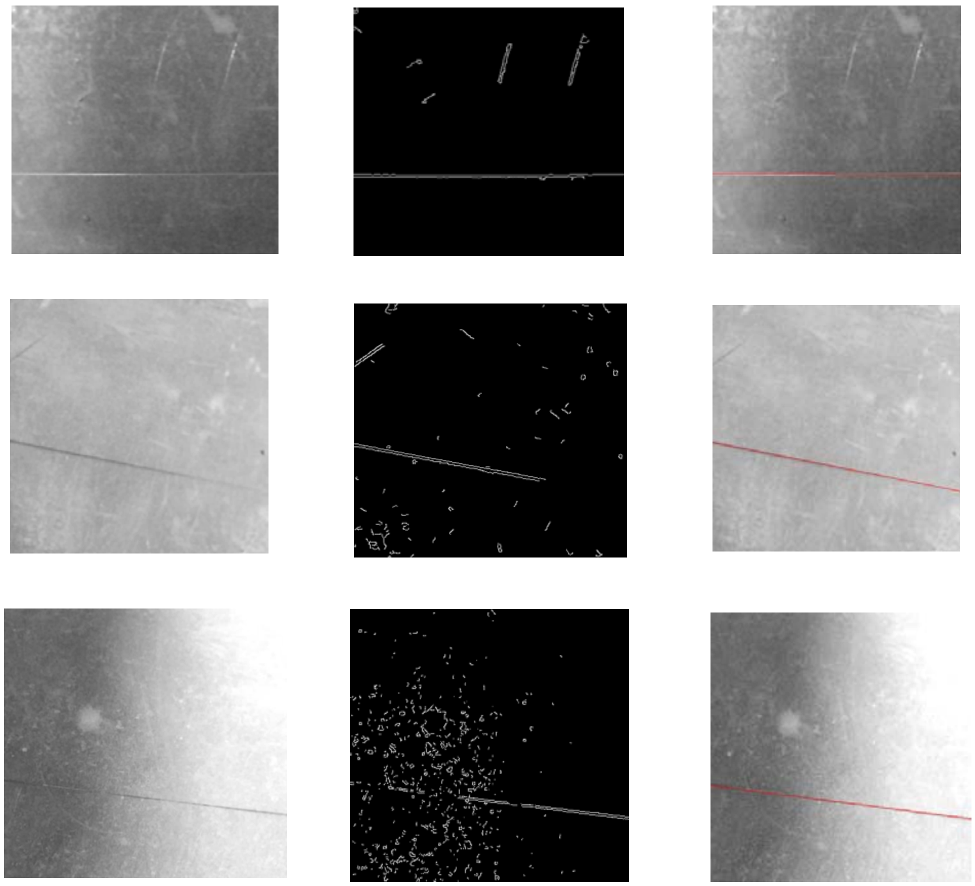

Fig. 4: Detection results of lanes with different jams

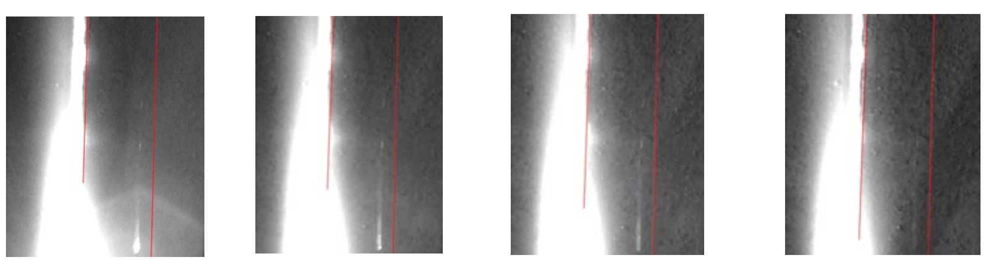

Fig. 5: Tracking results of the calibration line and the groove line (4 frames)

show that the process of tracking gradually becomes stable despite occlusions and scene change, the algorithm has better robustness.

The experiments in this study used the 3000 frame image for analyzing. If the ARHT detection algorithm is only used in detection, 2746 frames images can be detected accurately. The main false alarm occurs in the near flame. In order to improve the real-time performance of algorithm, the performance of PC is Intel Core 2, 2.00 GHz CPU, 2.0G memory. At this time the average speed of image processing is 12.8 frame/s. After adding the particle filter, the accuracy of groove line detection is raised to 94.3 percent. At the same time the information particle filter supplied helped Tabu search further reduce the search range. So the algorithm processing speed is raised to 14.2 frame/s. The experiments of real-time cutting indicates that this algorithm can work if the cutting speed is within 200 mm/min, more than this rate there will be intermittent frame missed.

CONCLUSION

In this paper we use the ARHT and Tabu search to solve parameter of the calibration line and the groove line, and combine with the tracking algorithm based on particle filter. In the cutting processing, the calibration line and the groove line can be steady and rapid real-time extracted. The large number of experiments verified that the algorithm is effective, fast and steady.

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