Comparative Analysis of Methods for the Log Boundaries Isolation

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Abstract The scrutiny of boundaries isolation methods is presented in this paper. The newly developed algorithms, based on regression analysis and integral projection are compared with Hough transform in order to analyze their effectiveness for the specific problem of moving logs control. The comparative analysis of the methods was carried out on the database of images obtained from video sequence of real industrial process by the criteria of accuracy and operation speed. Results of the test show that the line-by-line scanning method with posterior LOWESS regression analysis has the best accuracy. However, the best appropriate for the implementation in the real-time control systems based on machine vision technology is consecutive line selection method due to its reasonable accuracy and impressive performance.

1 INTRODUCTION

The main objective of this scientific research is development of real-time machine vision system analyzing the geometry and wood type of logs moving on conveyor belt. The procedure of analyzing is a set of actions for the video sequence of logs. This set includes selection of front-stage objects and a description of their parameters for each frame, such as the trajectory and velocity, and some attributes which are specific for each task (developing system requires the geometric characteristics of logs).

This work is devoted to the comparative analysis of boundaries isolation algorithms as applied to analyzed objects - logs. This task is complicated by the fact that in the process of removing the bark from the logs, some of it remains untidy, resulting in significant distortion of the shape of the log. The images of the log with bark remnants must be further processed in order to restore the true edges of the log.

Analysis of the literature on the problem of detection, isolation and determination of the geometric parameters of objects via video surveillance indicates that common methods and algorithms (Gonzalez, Woods, 2007) tend to be overly complex and unsuitable for use in machine vision systems operating in real time. Moreover, most algorithms are suitable only for specific applications and do not account for all possible situations that could arise during the technological process of logging, e.g. during transportation of logs on the conveyor.

2 EASE OF USE

According to national standard of round timber measurement methods – GOST R 52117-2003, there are several methods for determining the volume of log in Russia. Having regard to the possibility of high-speed image processing with the use of machine vision systems, the most accurate definition of timber volume can be achieved with the sectional method. The essence of the method is to calculate the volume of the log (V, m^3) as the sum of the volumes of sections of truncated cones along the length of the logs according to the formula:

$$V = \frac{3{,}1416 \cdot l_i}{12 \cdot 10000} \sum_{i=1}^{n-1} \left(d_i^2 + D_i^2 + d_i \cdot D_i \right) + \\ + \frac{3{,}1416 \cdot l_n \cdot (d_n^2 + D_n^2 + d_n \cdot D_n)}{12 \cdot 10000}, \quad (1)$$

where l_i – section lengths of a given size, m;

l_n – last section of length n, having a length less than l_i, m;

d_i, d_n – the upper diameter of the common section with given length and the one of the last, shorter section, cm;

D_i, D_n – the lower diameter of the common section with given length and the one of the, last, shorter section, cm.

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To isolate the boundaries of the log the following procedure have been analyzed:

- Hough method;
- line-by-line image scanning method;
- method of consecutive line selection.

2.1 Hough Method

In the context of the problem it is accepted that the edge of the log could be approximated with sufficient accuracy by a straight line or a piecewise linear function. One of the most effective methods of finding the straight lines on the image is Hough transform (Fig. 1). This method is implemented with the following guidelines (Forsyth, Ponce, 2003):

Reducing the influence of the insignificant points. Recommendation to reduce the influence of the noise component is taken into account at the stage of log's edge detection by the gradient operator. Under the assumption that the edges of logs orient mostly vertically, Sobel operator with a mask "East" + "West" was applied to accent boundaries. The result of the edge detector implementation to the binary image are shown on Fig. 1b.

Selection of the grid array. The choice of a large grid pitch leads to the situation when the weight can be mistakenly allocated to the cell which corresponds to a number of different lines, and at small grid pitch the weights of the points lying on the same line can be in different cells. Based on the problem specification and the existing image database the performance of Hough method was analyzed at the different values of grid pitch and threshold. The quality of the log edge detection assessed visually. The best result was achieved when the grid pitch value is 4 pixels, grid pitch angle is $\pi/18$ and the threshold is 200.

The result of the algorithm implementation is presented on the Fig. 1d.

Since the actual boundaries of the log may be warped due to the knots, bark and trunk bend the edges obtained by the edge detector are very noisy. It was found that the Hough transformation is very sensitive to the influence of distortion, which leads to an erroneous allocation and even skipping edges or finding several closely spaced lines with small deviation angle (Fig. 1c). Furthermore, the quality of the lines detection is also reduced in the case of the log inclination.

2.2 Line-by-line Image Scanning Method

To overcome the drawbacks of the Hough method, an algorithm for log boundaries isolation through line-by-line image scanning was developed. Assuming that the target object is extended and rectilinear and has vertical orientation, for each line of binary image the search of $x_{\_r}$ $x_{\_l}$ points relating to the right and the left boundary of the object respectively is implemented. The search begins on conditions that the weight of white dots corresponding to the width of the observed object at the current line exceeds a predetermined threshold. When the first required point $x_{\_i}$ is found its coordinates are stored in the stack, and the analysis of a set of points $x_{\_i+1}$ ... $x_{\_i+n}$ is carried out. If they all belong to the front-stage object, it is concluded that the observed object is a log, and the point $x_{\_i}$ - its boundary point for this line. Otherwise, the stack is cleared and the boundary search continues. As a result, after passing through all lines of the image two sets $M_{\_r}$ and $M_{\_l}$ containing the points of the right and left boundary of the log respectively will be received:

$$M_{\_r} = \{x_{r_1}, \dots, x_{r_m}\};\ M_{\_l} = \{x_{л_1}, \dots, x_{л_m}\} \quad (2)$$

where m - the number of lines in the image satisfying the threshold condition by number of white dots.

The obtained set of points $M_{\_r}$ and $M_{\_l}$ describing log boundaries may contain not only the points of the log edges, but include elements of the sets belonging to the edges of other objects, for example, bark or knots, distorting the shape of the log. The following approximation methods were used to exclude these elements:

- least-squares method;
- algorithm LOWESS.

The essence of the ordinary least-squares method (OLS) is to find the coefficients of the linear dependence when (3) has the smallest value.

$$F(a,b) = \sum_{i=1}^{m} (y_i - (ax_i + b))^2 \quad (3)$$

where (x_i, y_i) are coordinates of the points of the set $M_{\_r}$ or $M_{\_l}$,

This model can be extended to the case of polynomial approximation of higher power (k> 1). Fig. 2a shows the selection of a third-power curve (k = 3) for the one boundary of the log.

The evident advantage of the OLS method is low computational complexity which means small runtime. However, the method is quite sensitive to the great single spikes associated with errors in the identification and capturing of the data points. As is known, the OLS algorithm based on the assumption of independence and normality of the data distribution.

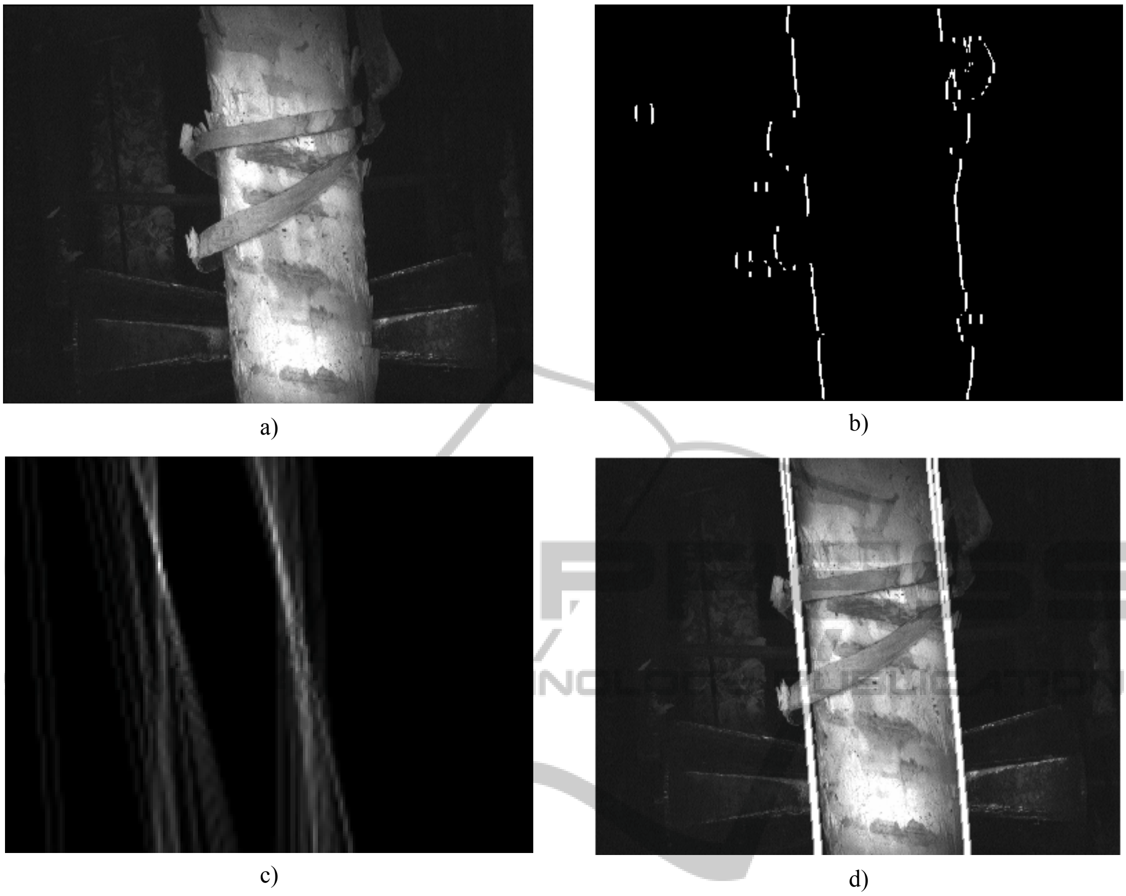

Figure 1: Illustration of Hough method. Origin image (a); image skeleton (b); Hough transform (c); final results of Hough method (d).

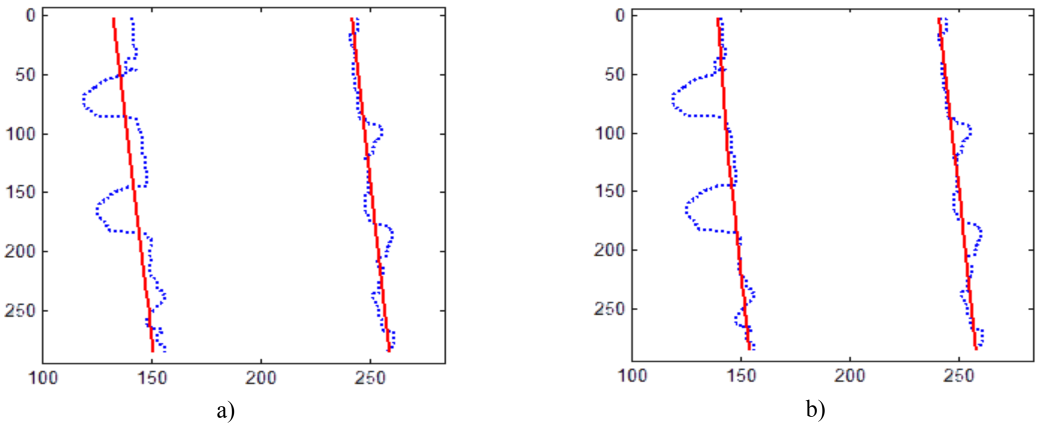

Figure 2: Results of the implementation of the line-by-line image scanning method with OLS (a) and LOWESS (b) approximation.

In this case, the assumption of normal distribution of the data is incorrect because outliers of the sample (points belonging to the bark or knots) are located mainly on one side. As a result, there is a significant departure of the approximating function from the true value. Least-squares criterion assigns large weights to the large objects and that is a serious problem in the allocation of the log boundary.

In order to reduce the sensitivity to distortions the method of robust nonparametric regression named locally weighted smoothing (LOWESS) was used. This technique was proposed for the simulation and smoothing of two-dimensional data (Cleveland, 1979). The basic idea of the method is in the assigning smaller weights to the sampling points with a large deviation and building of the linear regression on them. In other words, for a locally-linear model LOWESS, which can be written in the form $y_i = \alpha_i + \beta_i x_i + \varepsilon_i$,, we can show that the greater the error $e_i = |a_h(x_i) - y_i|$, the more probably the point (x_i, y_i) is outlier and its contribution to the final regression model should be reduced. This is an iterative operation, so the regression model is built and robust weights are refined for each sampling point at the each iteration until the weights become stable (Bendat, Piersol, 1993) (Fig. 2b).

Analyzing the results of applying the image scanning method to isolate the boundaries of logs we can conclude that:

- for the OLS method approximating function is shifted from the real boundaries of the log near the minimum and maximum values of x ("edge effect");
- LOWESS algorithm cannot be used in the real time systems due to high computational complexity.

Thus, the above disadvantages of the image scanning method hamper its implementation in real time machine vision systems to the problem of logs boundary detection.

2.3 Method of Consecutive Line Selection

To overcome these drawbacks of the regression analysis it is required to separate data points from noise. The solution of this problem can be found by the following algorithm, which results are presented in Fig. 3:

- the parameters of the observed object such as position and angle of the boundary lines trajectory are approximately determine on the basis of the analysis of the horizontal projection of the image;
- then small pitch in angle and position relative to the found trajectory the search of the line which has the best approximation to the data set of sample points is carried out. As a criterion for consistency the majority principle is used, i.e., line is considered as found if it is consistent with the most part of the points.

Simulation of this algorithm gives the values of the angle (3°) and shift (1 pixel) pitches that yield the best results both in speed, and quality of the log boundaries isolation.

Figure 3: Results of the consecutive line selection method.

3 TEST RESULTS

The described algorithms have been tested on the image dataset obtained from the video of the real technological process of the log passing down the conveyor. Total amount of testing frames is about 800. The test PC has the following characteristics: Intel Core i7 2.8 GHz, 4 Gb RAM and GeForce GTS 450. The results of the tests are given in the Table 1.

Table 1: Results of the algorithms testing.

Criterion	Hough method	Line-by-line image scanning method		Method of consecutive line selection
		OLS	LOWESS	
Mean square error, pix.	2,985	4,81	1,32	2,26
Maximum error, pix.	6	8,96	2,76	3,57
Computational complexity, ms	4-5	1	10-20	4-5

4 CONCLUSIONS

The tests show that the best result for the given real-time image processing task has the method of consecutive selection line. With the maximum error in the 3.57 pixels., the performance of this method is 5 ms for an image format of 576*768 pixels. The line-by-line image scanning method with robust regression, despite smallest error among the considered methods cannot be used in this problem because of the critical runtime performance – 20 ms for some cases, which is inappropriate for this implementation. In the systems which are less time-critical to the data processing, the most efficient use of line-by-line image scanning method with LOWESS robust regression.

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