The Algorithm and Software for Timber Batch Measurement by Using Image Analysis

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Abstract. This paper is devoted to the investigation and development of the round timber batch measurement technique on the basis of abuts detection and calculation of their diameters. The algorithm of abuts contours detection and refinement relies on the modified radial symmetry object detection. The meanshift clustering, Delaunay triangulation, Boruvka's minimum spanning tree algorithm, watershed and Boykov-Kolmogorov graph cut algorithm are implemented at the further stages of the algorithm. The testing of the algorithm gives its TPR value at 96.2% which is much higher than other unsupervised training methods. The software for the round timber batch volume measurement was developed on the base of the algorithm. An error of the software measurement in comparison with manual piece-by-piece approach is less than 7.07% with an average error of 4.9%. It meets the requirements of industry standards so the offered technique can be successfully applied in the activity of forest enterprises.

Keywords: Round timber · Volume measurement · Photogrammetry · Abut detection · Image processing · Radial symmetry · Mobile application

1 Introduction

The problem of the accurate accounting of raw materials and products is one of the most significant in respect to a constant struggle to minimize production costs. There are many different methods of measuring the timber volume, which differ from each other both in terms of physical principles and methods of volume management. The peculiarity of round timber is a high level of measurement error, which leads to a shortage or surplus in the revision of timber residues in warehouses and fluctuations in the consumption of timber during processing. Most methods for measuring the volume of round timber were developed more than 60 years ago [1]: piece-by-piece volume measurement, geometric group measurement, weight group measurement, etc.

The idea of the given method is to obtain the images of the timber batch ends with further processing of the photography by specialized software. During the image processing, the software produces:

– automatic detection of all visible abuts in each image;
– reconstruction of the 3D spatial structure of the timber batch;

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– calculation of the quantitative characteristics of each log and a batch as a whole.

The software for the mobile measurement of the round timber is designed on the basis of the described method and suitable for calculating a volume and geometry of timber batches. The software is designed to conduct operations with maximum possible automatic performance, however, the tools for manual editing of the processing result are also provided. The flow chart of the software processing is given in Fig. 1.

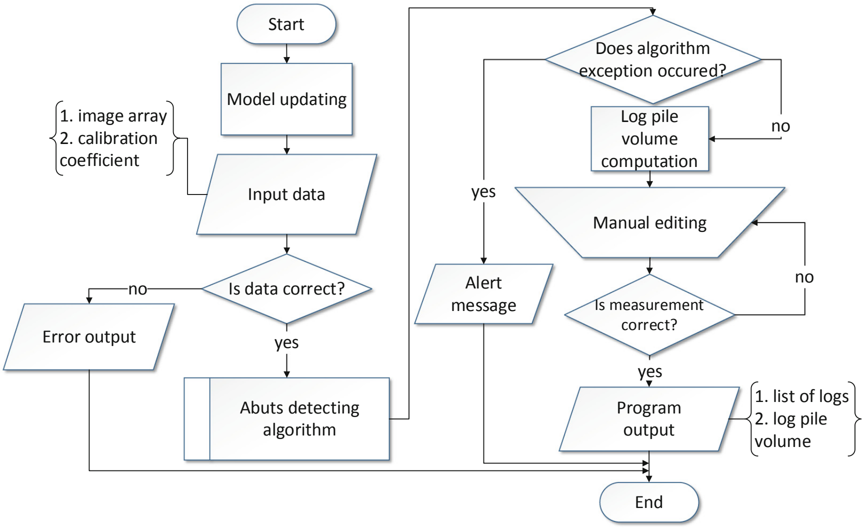


Fig. 1. Software processing flow chart.

2 Development of the Algorithm for the Automatic Abut Detection

As far as the algorithm for the automatic detection of the log abuts is the key feature of the software and the method in all it will be described more thoroughly within this paper.

The problem of the log abuts detection in the images was observed in several researches [2–6], and some of them have found practical implementation as a part of the applicable measuring system [5, 6]. Presented in those papers detection techniques could be divided into two categories. First group includes methods based on the machine learning. In [4] Herbon et al. describe the iterative algorithm for detection and segmentation which uses the descriptors of interest points based on histogram of oriented gradients (HOG) [7] in combination with Haar features and local binary patterns (LBP) at the stage of the log abut detection. Gutzeit and Voskamp in [3] applied Viola-Jones algorithm means for implementation of the cascade of the classifiers where each of them is the assembly of weak classifiers; the features for the detection algorithm are the rectangular Haar ones. Second group are the unsupervised training methods which used the assumptions of the form and size of logs [2, 6]. In general, these methods are based on the Hough transform [8–11] or its modifications and used to detect log abuts in the image in the form of circles or ellipses.

In the context of the given task the most appropriate detection method in terms of the computational cost and requirements to the possible distortions of the target objects is the one based on the evaluation of the fast radial symmetry transformation [12]. This method show high efficiency for the images with a priory known radii, low level of the form distortions and upon condition that the searching radii spread in a small range. However, it has some disadvantages that should be eliminated:

– The signal/noise ratio of the cumulative accumulator is significantly reduced with a large range of radii, resulting in complicacy of the potential circle centers detecting;
– Necessity of scanning the output for each radius after detecting of the potential circle centers in full transform output to compare responses in detected points for radii refinement.
– Choosing the optimal threshold for analyzing the spikes of the full transform output for specific image.

Thus for the abuts detection task the modification of the radial symmetry object detection method was implemented in reliance on the above (see Fig. 2).

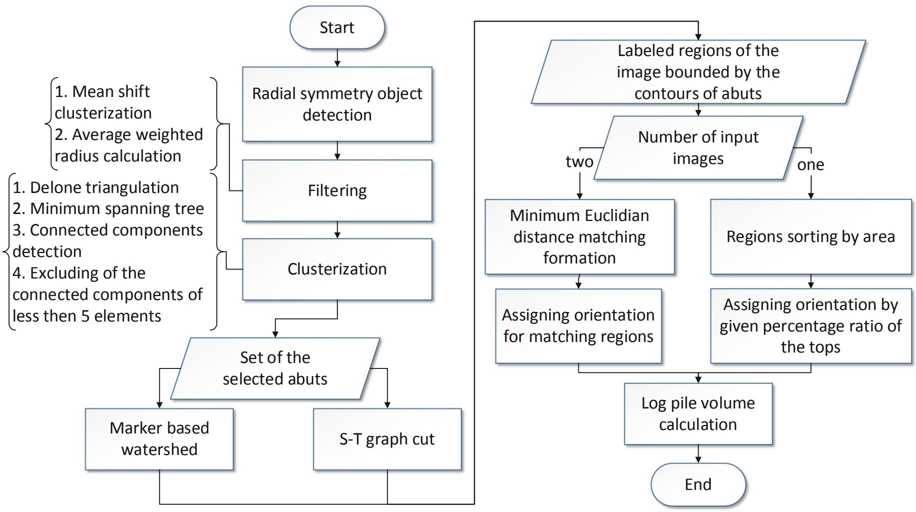


Fig. 2. Algorithm control-flow chart.

2.1 Object Detection

The detection stage involves the finding in the image all possible target objects which meet a number of criteria. The aim of the detection is to obtain the primary input data about measuring objects and select the necessary sets of features for further classification and segmentation. Analysis of the considerable number of the batch images shows that the most abuts have approximately circular form (Fig. 3).

a b

Fig. 3. Examples of the timber batch images.

The magnitude projection image is not constructed as far as detector decisions are made on the basis of the modified orientation projection image analysis. First stage of the detection is the Sobel operator implementation for the boundary pixels recognition, which estimates the magnitude and the direction of gradient vector. The voting boundary pixels are the ones with the high value of the gradient magnitude. After that the gradient vector direction is estimated for each boundary pixel in order to calculate the center of circle of the specific radius.

At second stage the search of the local maximum in the orientation projection is implemented. The algorithm splits the set of search radii into non-overlapping ranges to provide invariance to the image scale and target objects form distortions. Each range covers the specific scale interval and has its own size of the filter. It was decided to calculate the specific size of the scanned aperture as function of search radius according to the formula:

$$A_r = \begin{cases} [\log_{10} Sq_r] & \textit{for odds} \\ [\log_{10} Sq_r] + 1 & \textit{otherwise} \end{cases} \quad (1)$$

where [] – integral part of a number, Sq_r - area of the circle of radius r.

The idea of the optimal threshold selection is that it can be evaluated from the result of the algorithm implementation to the image of the same size and brightness arrangement as the initial one but containing no radial symmetry objects. The value of the optimal threshold depends on initial image entropy, thereat the threshold for the segmentation of the initial image orientation projection can be selected as following:

$$T_r = \max(\tilde{O}_r) + A_r^2 \quad (2)$$

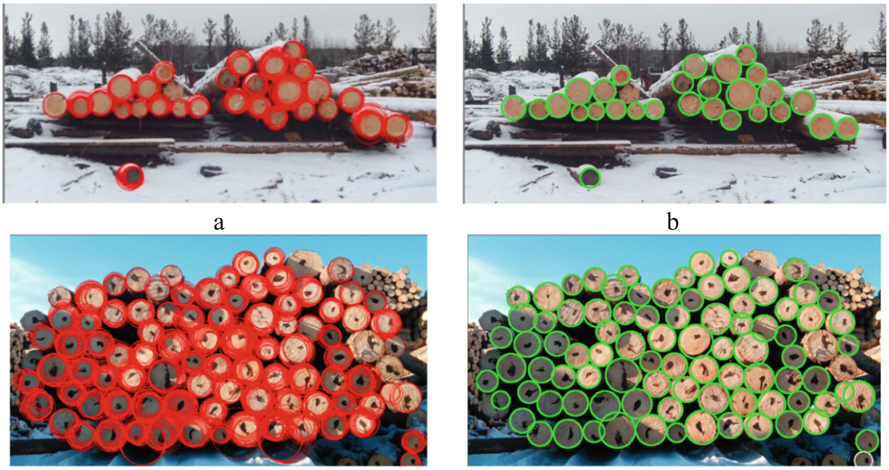
where $\max(\tilde{O}_r)$ – global maximum of the «noise» projection image scanned by A_r.

A_r in the formula (1) can be interpreted as correction scale coefficient. The descriptor of the region of interest of specific radius r with the scale invariance is calculated as following

$$D_r(x, y) = O_r(x, y) - T_r \quad (3)$$

where $O_r(x, y)$ – local maximum with coordinates (x, y) in the projection image of radius r scanning with aperture A_r, T_r – optimal threshold for the radius r.

Thus the offered method solves two problems: the search of the target objects with radial symmetry and the computation of their descriptors with scale invariance. It means that the value of the interest point for orientation projection of radius r_1 is the same as the local maximum in accumulator of radius $r_2 (r_1 \neq r_2)$. The greater the value of the descriptor (weight of the object) the more accurate the target object form matches the circle. This approach allows selection of the best candidates among the obtained objects. The result of the modified detection algorithm is shown in Fig. 4a and c. Inasmuch as cross-correlation of the near-by search radii has negative impact on the result (there are many overlapping circles in the Fig. 4a and c) as well as prominent medulla of the abuts, the filter function should be introduced.



a b c d

Fig. 4. Implementation of the modified detection algorithm

The meanshift clustering [13] is implemented to the output transform of the modified detection algorithm. The average weighted radius is calculated for each cluster:

$$r_{aw} = \sum\nolimits_{i=1}^{n} r_i \cdot \omega_i / \sum \omega_i \quad (4)$$

where n – cluster cardinality, ω_i – weight function: $\omega_i = l_{r_i} \cdot n_{r_i}$

where l_{r_i} – radius, n_{r_i} – number of radius of given length in the cluster.

Result of the filtration is shown in Fig. 4b and d.

2.2 Clustering

Clustering solves the problem of grouping the set of the objects obtained at the previous stage into the disjoint subsets of the target and nontarget objects. For the problem of the timber batch volume measurement the aim is to divide the detected objects into two subsets – «batch» and «non-batch». In such a way the image regions which are selected at the detection stage but not related to the target objects will be excluded before the segmentation and measuring.

Firstly it is necessary to construct the feature set and metrics based on the purpose of the clustering. The useful assumption is that the logs in a batch displayed in a feature space as a closely adjacent points. It is evident that the closer objects to each other the higher probability of their belonging to the same group. Thus the geometrical similarity metric (log density) was introduced to solve the clustering problem. This metric defines weather the log belongs to the batch or not. Among the existing clustering methods [14] the graph one was selected due to its clarity and simplicity.

The following algorithm is implemented to the set of the detected objects:

1. Iterative Delaunay triangulation [15] with dynamic caching [16],
2. Finding the minimum spanning tree through Borůvka's algorithm [17];
3. Cut of the tree along edges until the condition (5) is reached.

$$\max_{(v,u)\in E} c(v,u) < 2 \cdot \max(r_{aw}) \tag{5}$$

   where E – set of the graph edges, $c(v,u)$ – weight of the edge (its length in this case), r_{aw} – the average weighted radius (4)

4. The criteria for the obtained connected components $G(V_i)$ to be included into the final sample $G(V)$ is the following:

$$G(V) = \bigcup G(V_i) : |G(V_i)| \geq 5 \tag{6}$$

The result of the clustering is shown in Fig. 5.

a b

Fig. 5. Structure of the batch determined by the graph algorithm.

2.3 Segmentation

Segmentation is carried out to refine the contour of each abut and to extract feature set for further timber batch volume measurement. The segmentation algorithm relies on the combination of two methods: marker-based watershed [18] and Boykov-Kolmogorov algorithm of the minimum s-t graph cut [19]. Watershed algorithm is used to specify the regions where abuts are located. At that an approximate boundary of each object is known as far as it is the average weighted radius r_{cp} that should be rectified.

For min-cut/max-flow algorithm the area for source node selected within less than $1/2\, r_{aw_i}$ whereas the sink node area is farther than $3/2\, r_{aw_i}$ from mass center d_i. The conclusive region corresponding with abut in the image is determined by the combination of the watershed and s-t cut outputs:

$$G(V)_i = G(S)_i \bigcap W_i \tag{7}$$

where $G(V)_i$ – region of the abut i, $G(S)_i$ – region of the abut i according to the s-t cut output, W – watershed basin containing marker i.

3 Manual Editing

After the automatic algorithm execution some abuts may be undetected while other objects in the image may be detected incorrectly, so the manual editing should be implemented. In order to add new object in the image the tool “+” should be selected. Then the new object will be added after clicking in the image area. Deleting of the objects is implemented by selecting “–” tool and clicking objects in the image. In order to exit from current mode user should click the active tool again. Addition of the objects is implemented on the basis of the Lee algorithm [20]. Also manual editing allows user to resize objects when they are activated. In this case the anchor points of the ellipse become available so user can stretch, rotate or relocate it. Also the tools for additional log parameters adjusting become available: abut number, timber species, log length and orientation (see Fig. 6).

Automatic orientation (top or butt) is assigned for each abut according to the following rules:

In case of two images processing the orientation is determined by comparison of two abuts for each log and bigger one is labeled as butt whereas smaller – as top.

In case of one image processing orientation is assigned selectively on the basis of the area of the image regions related to abuts and specified percentage ration of the top abuts. In this mode the manual editing of the orientation is provided: after the particular abut is selected the tools “Top” and “Butt” (displayed as letters “K” and “B” respectively, see Fig. 6) are appeared in the workspace and user can assign the orientation of the abut.

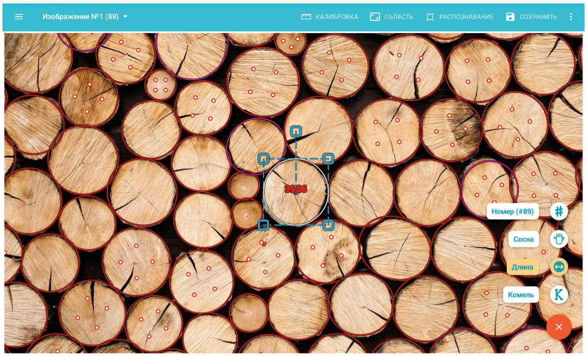


Fig. 6. Manual editing tools for specific abut: abut number, timber species, log length and orientation

4 Testing and Results

The testing of the algorithm was carried out on the tablet Samsung Galaxy Tab 3 GT0P5210 16 Gb 10,1". Requirements to the picture taking are the following: camera is parallel to the abuts plane, the batch is located at the center of the frame with space between the frame edge and the nearest abut. There were 940 measurement of the 632 piles under the different conditions during the algorithm testing.

Results of the testing show that the offered algorithm based on the modified radial symmetry detection method reaches higher performance in comparison with methods based on linear classifiers and weak classifiers cascades. Also the offered algorithm is outperformed the methods based on Hough transformation (see Table 1).

Table 1. Comparison of the methods

Method	TPR (σTPR), %	Method	TPR (σTPR), %
LBP [4]	95,8(3,7)	LBP+HAAR+HOG [4]	98,4(2,1)
HOG [4]	77,9(10)	CHT+LCM [3]	90,8(9,4)
LBP+HOG [4]	96,0(3,1)	CHT [3]	84,8(11,6)
HAAR [4]	95,1(3,8)	LCM [3]	89,7(9,8)
HAAR+HOG [4]	96,0(3,5)	**Our**	**96,2(4,1)**

On the other hand the algorithm is inferior to the methods described in [4] when the last are strengthened by the combined classifiers and considered the abuts textural information. In spite of high rate of TPR this method has much higher computational complexity which is sensitive for its implementation for mobile devices.

After the analyzing of the algorithm output the results of the round timber batch measurement manually edited by the software tools were compared against piece-by-piece measurement (see Fig. 7).

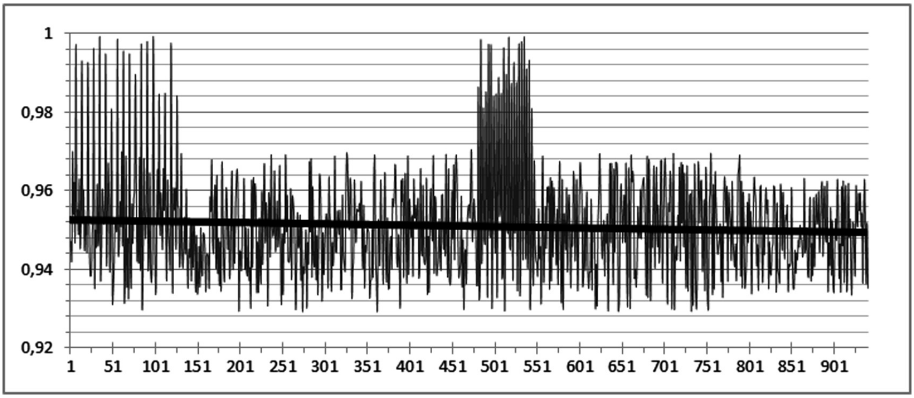


Fig. 7. Relative accuracy of the algorithm output in comparison with manual piece-by-piece measurement.

5 Conclusion

As a result of the proposed methodology, the measurements of the round timber will be made faster in comparison with other approaches (manual measurement, weighing), whereas their results will become more reliable (re-verification of the measurement, reducing the possibility of falsification). Mobility and speed of the given solution allow user to perform measurements in places of logging, on the truck, during the shipment-acceptance or sending for further processing. That is, to account for raw materials at every stage of its life cycle. Implementation of the developed software makes it possible to automate previously unavailable parts of the production process, which leads to higher labor discipline of personnel, lower costs for traditional (paper) communications between company divisions (an average of 67%) [21] and a decrease in the time of accounting operations (an average of 36%, in the range from 0 to 90%).

The maximum error of the software for the timber batch volume measurement is less than 7.07% with an average error of 4.9% (see Fig. 7). The tolerance of the measurement of the same batch from the different viewpoints is less than 1%. Thus, the method of the timber batch measurement using the developed algorithm can be successfully applied in the activity of forest enterprises as far as industry standards establish the maximum volume measurement error for the round timber accounting in the range between ±3% and ±12%.

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