PHOTOGRAMMETRIC TECHNIQUES FOR MEASUREMENTS IN WOODWORKING INDUSTRY

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ABSTRACT:

Accurate measurement of wood volume is a very important task at each stage of woodworking process beginning with estimation of volume of cut trees and finishing with determining the volume of resulting product. In most cases, current technology of measurement is based on inexact manual procedures and gives rather rough data. To introduce a new measurement technology in woodworking industry 3D imaging techniques are developed for two general stages of woodworking: for volume estimation of tree packages coming to logging enterprise and for volume determination of a log moving on a conveyor belt.
The system for cut tree packages estimation is based on stereo image acquisition of the front view of the tree package and calculation of the area of log cuts. The developed methods for cuts measurements are discussed. For log volume determination during conveyor wood processing a technique based on moving log image acquisition in stripe light is developed. It allows generating a 3D model of the log which is used for volume estimation.
The paper describes the developed methods of 3D measurements, outlines of the hardware used for image acquisition and the software realized the developed algorithms, gives the productivity and precision characteristics of the system.

1. INTRODUCTION

The problem of accurate measurements in logging and woodworking industry is very important and actual. 3D imaging technique gives wide opportunities for solving this problem and could be applied at any stage of wood processing. One of the processes, which demands for accurate and fast performing, is determination of cut trees package volume carried by the truck (Fig.1.). In most cases measurements requires an operator as a key element. The operator measures the width and height of front area with a ruler and manually writes the measured values into notebook. Then the volume of the package is estimated using empirical equation. The procedure seems to have low accuracy, low productivity and good background for man-made errors.

Figure 1. Cut trees package to be measured

The proposed system for cut tree packages estimation includes a set of CCD video cameras, PC equipped with frame grabber and original software for image processing and 3D measurements. Two methods for measuring are developed and discussed. The first one is based on stereo matching of the tree package images and model based tree cuts extraction. The second approach uses image orthotranformation into front plane to obtain rectified image which is more convenient for processing. This technique allows processing transformed image for ellipsoidal shapes detection and calculating their area. The developed algorithms for shape extraction provide high robustness. They are based on modified Hough transformation technique and computational geometry algorithms for convex hull generation.

Another problem which requires automated non-contact measurement solution is volume determination of a log moving on conveyor belt. The technique for a log volume determination is based on lighting the log by bright stripe during its movement along a conveyor. It allows real-time calculating a set of the log's profiles with frame rate frequency and to generate a 3D model of the log which is used for volume estimation. Special cameras calibration procedure is developed for providing metric characteristics of the system.

The image-based 3D-measurement system is proposed as an alternative for manual measurement. The main requirements to the developed system are following:

- high precision of 3D measurements
- high productivity - capability of fast measurements
- support of on-line and off-line mode
- support of automated measuring mode

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- support of manual mode for 3D measurements
- capability of measurement of area of every cut tree in package
- capability of measurement of area of polygon including all cut trees in package
- capability of calculating the number of trees in package
- capability of modification into real-time measurement system

Below the developed methods of 3D measurements are described along with outlines of the hardware used for image acquisition and the software realized the developed algorithms.

2. SYSTEM OUTLINE

2.1 Hardware configuration

The proposed volume measurement techniques were developed using laboratory photogrammetric system operating with model wood logs and wood packages of the scale factor 1:10 (the real size of objects to be measured being in range of 2.5-3.0 m.). The laboratory system is based on PC as central processing unit and non-metric CCD video camera as image acquisition device.

It includes:

- Pentium4-1.4/512MB PC
- 2 high resolution PULNiX CCD cameras equipped with 12-mm focal length lenses
- 2 channel PCI frame grabber
- Laser stripe line projector

The PC is equipped by frame grabber providing simulations two channel image acquisition and on-board stripe light detection function. The view of laboratory system is shown in the Fig. 2.

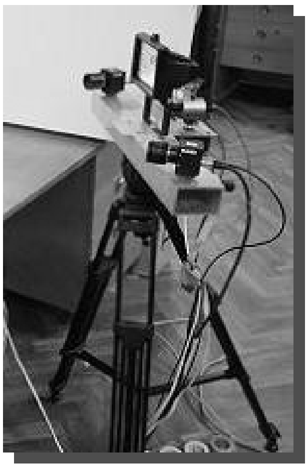


Figure 2. The view of laboratory system

The system is designed for working space of 300x300x200 mm dimensions.

2.2 System calibration

As long as laboratory system uses non-metric cameras for measuring purposes the preliminary cameras calibration is performed. The original calibration procedure based on images acquisition of planar test field is fully automated as a result of applying coded target for reference point marking (Knyaz V., 1998; Knyaz V.,2002).

Calibration includes two stages: a) interior camera parameter determination and b) system external orientation. As a consequence of first calibration stage the parameters of interior orientation (principal point x_p, y_p, scales in x and y directions m_x, m_y, and affinity factor a, the radial symmetric K_1,K_2,K_3 distortion and decentering P_1,P_2 distortion) are estimated.

Precision results (standard deviation) of interior orientation estimation are given in table 1:

spatial reference points coordinates	σ_{xs} = 0.011 mm
angle exterior orientation parameters	$\sigma_{\alpha\omega\kappa}$ = 0.038°
residuals of collinearity conditions	σ_{l0} = 0.034 mm

Table 1. Precision of interior orientation

The exterior orientation procedure (second stage) is performed using the same planar test field for estimating unknown relative orientation parameters: (X_1, Y_1, Z_1) – location and ($\alpha_1,\omega_1,\kappa_1$) and angle position of the left camera and (X_2, Y_2, Z_2) – location and ($\alpha_2,\omega_2,\kappa_2$) and angle position of the right camera relatively external coordinate system origin defined by test field. The residual of collinearity conditions for external orientation procedure is 0.04 mm.

The results of calibration demonstrate the reasonable accuracy for task of 3D measurements.

To support the proposed technology original software for WindowsXP is developed. It provides the complete technology of 3D measurement:

- image acquisition
- system automated calibration
- image processing for feature extraction
- calculating the required characteristics and report generation

3. PACKAGE AREA MEASUREMENT

3.1 Measurement techniques

Two approaches for automated front area of a package measuring are developed. The first approach is aimed on recognising all ellipses (log cuts) in two images and establishing correspondence between the found circles. Then area of spatial circle can be determined. This approach has problems for convergent image acquisition when the circle looks like ellipse (Fig. 3.) and the problem of ellipse recognition is more complicated then circle extraction.

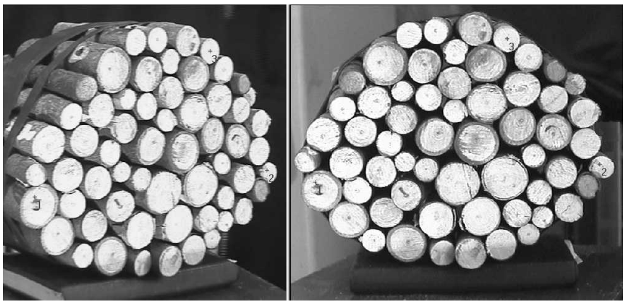


Figure 3. The stereo pair of package scaled model

The second approach is based on an assumption that all cuts (circles) lie approximately in one plane. Then image orthotransformation to this reference plane gives metric scaled map of the front side of package with known scale factor. So it is possible to perform plane measurements to have adequate results.

Figure 4. The orthophoto of the package scaled model

Fig.4. presents the orthophoto of the package produced basing on the reference plane and left image. In the orthophoto the cuts look like circles.

The algorithm for automated circles recognition in the images was developed. It was used for cut detection and subsequent measurements. Below the description of image analysis algorithm is presented.

3.2 Image analysis algorithm

The image analysis algorithm based on the original circle detection technique (Knyaz V., 2000). The complete procedure of image analysis for one frame includes the following steps:

1. Forming of intensity gradient field
2. Testing hypotheses from discrete space of circle parameters (2x2D-accumulator)
3. 2x2D-accumulator analysis: determination of circles' locations
4. Constructing a minimal convex covering for a set of extracted circles
5. Reconstruction of non-detected circles
6. Computation of required area parameters

These steps are briefly described bellow.

3.2.1 Forming an intensity gradient field: The intensity gradient field is implemented as two 2D arrays: array of gradients in x-direction and array of gradients in y-direction. It is formed as follows:

- Evaluation of gradients by Sobel operator;
- Elimination of weak gradients;
- Thinning of gradient field.

The Sobel operator is a well-known image processing procedure. It allows the determination of both magnitude and orientation of image intensity gradients at the each pixel of image. Elimination of weak gradients means that the elements of gradient field with gradient magnitude less than some threshold to be set to zero.

Thinning of gradient field is a procedure that eliminates all points of gradient field those are not the local maxima in their directions. This procedure makes the contours of objects as sharp as possible. Practically, at this stage, the gradient field may be considered as a contour image supported with gradient values at each contour point.

3.2.2 Testing hypotheses from discrete space of circle parameters (2x2D-accumulator): At this step, the each point of area of interest is tested as a possible center of circle. This testing presumes the following operations:

- Collecting a number of appropriate contour points for each value of possible circle radius in some given range;
- Normalizing this numbers as percents of circle length for corresponding radii;
- Finding the best radius that corresponds to the maximum percentage value.

The "appropriate contour point" means here that the angle between the radius vector from this point to center point and the gradient vector in this point is small enough. Normalizing of numbers is performed, because the possible number of points on discrete circle depends on its length.

The best hypothesis for tested point is stored in a special 2x2D-accumulator. The accumulator of hypotheses is implemented as two 2D-arrays those geometry corresponds to the geometry of source image. One accumulator array R(x,y) contains the radius of probable circle for this center point (x,y) and the other array N(x,y) contains the corresponding number of points on the circle contour.

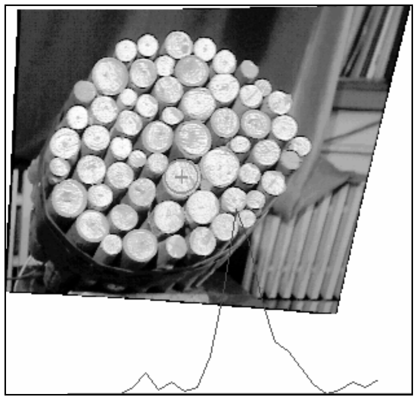


Figure. 5. Example of function of a number of appropriate contour points for each value of possible circle radius

3.2.3 2x2D-accumulator analysis: determination of circles' locations: The procedure of 2x2D-accumulator analysis performs the iterative search of local maxima according to the following algorithm:

Step 1. Find the global maximum of N(x,y) array
Step 2. Put the circle with (x,y) center and R(x,y) radius into the list of circles.
Step 3. If (N(x,y)/R(x,y)<Percentage_Ratio)
then
stop the search.
else
clear the accumulator in the round neighborhood of (x,y) with R(x,y) radius and go to step 1.

This procedure starts from big circles and proceeds to small circles until all appropriate candidates in the accumulator will be put in a list.

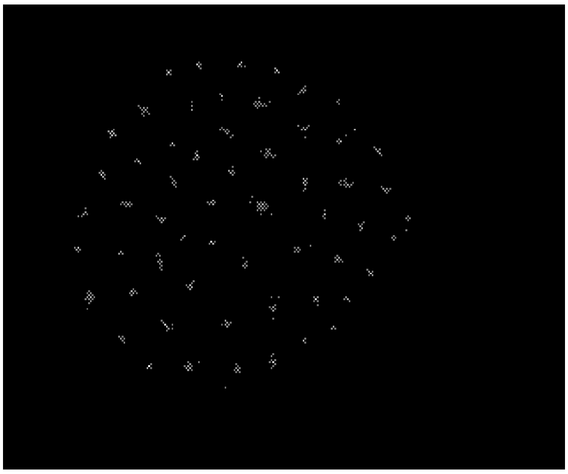


Figure.6. The structure of accumulator for circle hypotheses.

3.2.4 Constructing a minimal convex covering for a set of extracted circles: It is a standard procedure of computational geometry. The only modification of it in our application is connected with a fact that we deal with circles but not with points. Due to this fact, the convex covering should consist the arcs of circles as well as segments of lines between them. However, we use the approximate computational scheme that allows representing the convex covering just as a closed polygon without arcs. This approximate procedure is performed in three steps:

- Find the minimal convex covering to a set of circle centers;
- Find the mass center of vertices of this covering
- Expand this covering by translating the each its points by vector from mass center with length of circle radius at this point

Our experiments have demonstrated that the precision of such approximation is appropriate enough for this application.

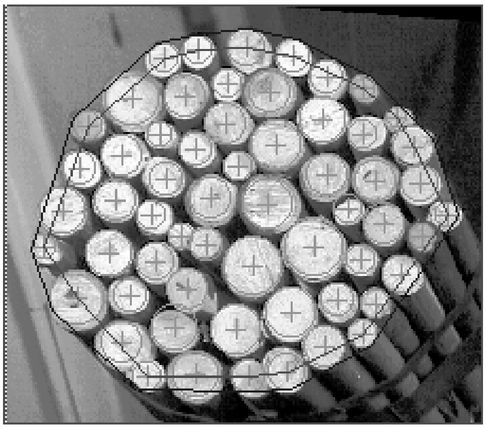


Figure. 7. Minimal convex polygon (blue) as an expansion of minimal convex covering for set of centers (red).

3.2.5 Reconstruction of non-detected circles: As we state in the previous section, our approach is based on an assumption that all cuts (circles) lay approximately in one plane. However, it the real cuts may not satisfy this condition. Therefore, on the ortho transformed image some cuts will screen the other cuts. If the big cut screen the small cut, the small become “invisible” for the detection algorithm due to low number of visible points on its contour. Fortunately, these «invisible» objects make the “holes” in the entire structure of the circle set. In our algorithm, the holes inside the covering polygon are detected to recover the lost cuts (circles).

Sometimes this recovering algorithm fails, when it try to fill the hole from one lost circle by two or even three smaller circles (if the environment allows such decision). However, the estimation of sum of cuts’ areas still better that for the case without recovering of lost circles.

3.2.6 Computation of required area parameters: Finally, three basic characteristics of the bundle are calculated:

- The number of cuts in a bundle
- The total area of cuts in a bundle
- The area of bundle bounded by a minimal convex polygon.

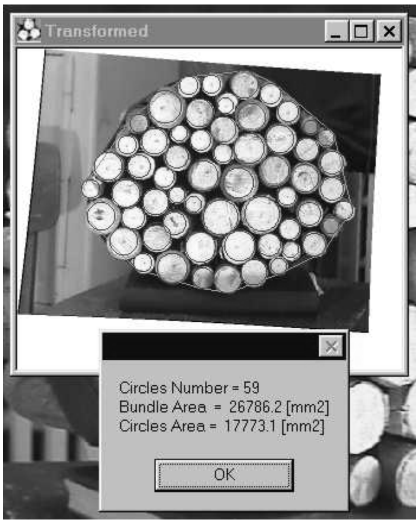


Figure. 8. The final result of the computations.

3.2.7 Manual measurement mode: The system designed for working in off-line mode to process previously acquired and stored images in automated, semi-automated or manual mode. In semi-automated mode software recognize any single circle in the orthophoto and find its diameter and area. To find the area of single cut operator has to mark it by mouse click. The recognized circle is displayed and its parameters are shown in message box. The result of semi-automated cut extraction is shown in Fig. 9. in “Transformed” window and “Measurements” message box. Operator also can delete false recognized cuts (if any) and store results in report file.

In manual mode operator can perform any 3D measurements basing on given stereo pair. He can measure 3D coordinates of spatial point marking it in the left and right image. For determining distance between two spatial points the corresponding image points have to be marked in the left and right image. Fig.9. illustrates distance measurement. Markers #1 and #2 determine the diameter of the same cut as extracted in orthophoto. The result of measurement is given in untitled message box in the left image.

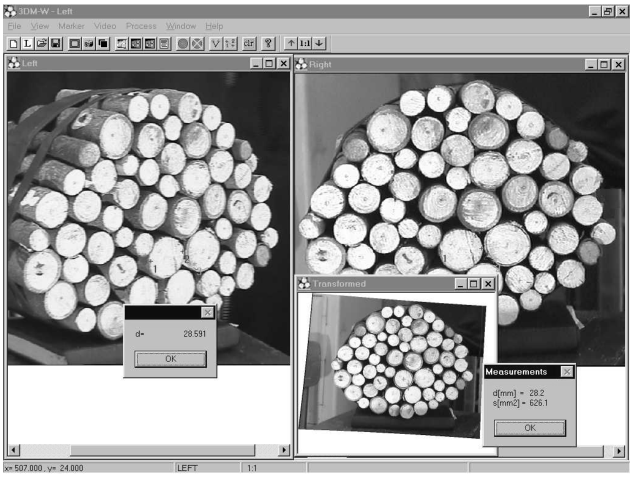


Figure. 9. Manual mode measurements

The precision of manual measurements is higher then obtained by automated procedure, but manual mode is sufficiently slower and can include operator's errors.

3.2.8 Stereo pair measurement technique: For circles detection in this method the above described algorithm is used. After circles detection their stereo matching is performed using epipolar geometry and determined image size of detected circle. For candidates with similar parameters the choice is performed on condition that spatial circle has to lie near middle plane of all reliable circles. The comparison of results for two different area estimation techniques show that both methods give adequate estimation for cuts area but method based on orthotransformation technique is more robust and fast.

4. LOG VOLUME MEASUREMENTS

Another important task is volume measurement of a log moving on a conveyor belt. The real conveyor of log processing is shown in Fig. 10. The workspace does not allow seeing the whole surface of the log. So for volume estimation the following technique is proposed. A log is lighted by stripe line during its movement along the conveyor and images of the log in this light are acquired with camera frame rate. It allows real-time calculating a set of log's profiles with frame rate frequency and to generate a 3D model of the log which is used for volume estimation.

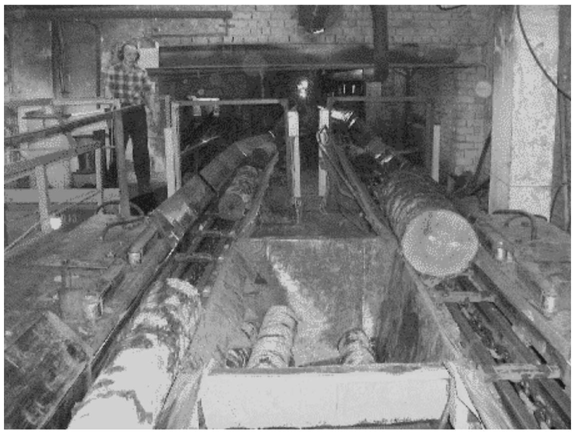
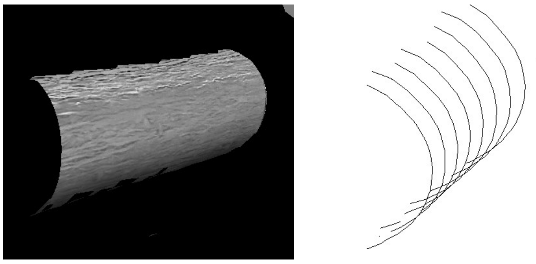


Figure 10. Log processing conveyor

The laboratory model of conveyor is used for the technique development. The result of log surface reconstruction using one camera is presented in Fig.11. Fig. 11a demonstrates that one camera allows to reconstruct approximately 30-40% of the log surface. This information can be used for circle approximation of the log sections and its volume estimation. Fig. 11b shows several reconstructed sections of the log.



a b

Figure 11. Log 3D model

The results of log volume estimation by described technique for a set of 50 logs were compared with independent measurements. The precision of non-contact measurements was at the level of 9%.

5. CONCLUSIONS

Automated non-contact photogrammetric techniques are proposed for measurements in woodworking industry. Two methods for logs package area measurements are proposed based on image processing for circles detection. The precision of both methods are similar, orthotransformation technique being more robust and productive.

In automated mode the performance of 3D measurements is about 8 seconds per package, the accuracy of measurements is at the designed level of 1 mm for the described laboratory system configuration. These characteristics are quite enough for today needs of wood industry. All measurements can be performed by "one-button-click".

The system for cut area measurements can be applied in off-line mode acquiring images and saving them for further processing in automated or semi- automated mode. On the current stage of system development semi-automated mode is more reliable and precise due to operator control of circles extraction. The accuracy of measurements in off-line mode is at the level of 0.1

mm for laboratory system. Including additional processing based on stereo information will allow increasing reliability and precision of automated mode.

The method for volume estimation of log moving on the conveyor demonstrates reasonable precision even in case of using one camera for surface extrapolation. The precision can be improved by using two cameras system.

The results of laboratory system application for log models demonstrate that the developed techniques provide high accuracy of measurements and reasonable performance. The higher characteristics can be reached by using more powerful processor and applying sensors of higher resolution. The developed digital close-range photogrammetric system has built-in capabilities for full automation and real-time processing.

6. REFERENCES

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