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Extraction of Trees Stem Diameters at Breast Height by Terrestrial Laser Sensor for Selective Cutting

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Abstract: In order to assist the operators of the logging harvester automatically and quickly select the appropriate trees for selective cutting, using two-dimensional laser scanner and inertial measurement system, the two-dimensional cloud points of the trunks at breast-height are obtained for several trees. After projection, clustering, linear transformation and fitting for the point clouds data, the parameters of the breast-height-diameters and center locations of the trees are obtained. The calculation is implemented in MATLAB by Polak-Ribiere-Polyak (PRP) conjugate gradient algorithm and the result is shown in VC++ environment. Using this method, absolute errors of the breast-height-diameters and center locations are 2.3 cm and (12.4, 11.4) cm respectively, and meet the requirements on the automatically selective cutting of the logging harvester.

Keywords: Laser measurement, Selective cutting, Plantation forest.

1. Introduction

With the development of the hydraulic control, more and more logging harvesters are used in forestry [1-3] to replace hand-operated felling machines and tools. The logging harvester can achieve successive works of felling, delimbing, measuring and bucking, and is very suitable for the large scale lower costs cutting operation in the fast growing plantation.

For the appropriate selective cutting of the forest, It is significant to find an efficient method to measure breast-height-diameters and location of surrounding trees contribute to the harvesting head to achieve automotive capturing and selective cutting.

Laser scanner is non-contact measurement system. The distance between the laser scanner and the object is determined by the time of flight of infra-red laser light pulses: a pulsed laser beam is emitted and reflected if it meets an object. From those distance data, a point cloud is created describing the shapes of the objects surrounding the scanner. Terrestrial laser scanning offers new possibilities in tree measurement applications in forestry [4].

In the last decade, different methods are used to achieve the trees information from the laser point clouds. Yili Zheng, Jinhao Liu et al. [4] get the cloud points of trunks by 2D terrestrial laser scanner and calculate the radii and center locations of the trunks by the Fletcher-Reeves conjugate gradient algorithm. David Kelbe, Paul Romanczyk et al. [5] develop automatic tree stem and DBH modeling approaches for single laser scans collected from an off-the-shelf SICK LMS-151 laser system. Jaakko Jutila, Kosti Kannas et al. [6] discuss the method on diameter and location measurement of tree parameters by 2D Laser scanner mounted on a mobile ATV platform. Thies Michael, Pfeifer Norbert et al. [7] use 3D terrestrial laser scanner to capture the geometric aspects of a tree: the radius, length and diameter of the trunk and individual branches. Matti Öhman, Mikko Miettinen et al. [8] use the 2D scanning laser range finders, machine vision systems and GPS to get information about the surrounding forest, such as tree diameters, positions and stem density.

In this paper, a 2D laser scanner and an inertial measurement system are used to get the point cloud of the surrounding trees; the cluster algorithm and filtering algorithm are used to extract each trunk from the point cloud, and the breast-height-diameters and location of the trunks are calculated by the PRP conjugate gradient algorithm. The calculation result is shown by mixed programming of VC++ and MATLAB.

2. The Description of the System

A 2D laser scanner LMS291 of SICK Inc. is used as the primary sensor. The surrounding measurement data is scanned by the LMS291, and is output in binary format via the RS485 data cable at the rate of 10 Hz to form the raw point cloud. The scanning angular resolution of the LMS2291 is set to 0.25°, maxim scanning angle is 100°, and maxim scanning distance is 8 m. As a result of the beam geometry, the maxim space between two laser beams and the measurement accuracy are in relation to the scanning angular resolution and maxim scanning range.

The whole measurement equipment is shown in Fig. 1, and the laser scanning in the plantation forest - in Fig.2.

Fig. 1. The hardware of measurement system.

The 2D laser scanner LMS291 is installed on the tripod with telescopic legs, and a miniature inertial measurement unit (MTi of Xsens, Inc.) is fixed on the top of LMS291 to measure the tilt and orientation angle of the scanner plane. MTi is capable of outputting roll, pitch and yaw of the scanner plane in real time via the RS232 data cable. LMS291 and MTi are powered directly from a 24 V lead-acid battery. The data analysis software is implemented on the computer by mixed programming of VC++ and MATLAB.

3. Extracting Breast-height-diameters for Selective Cutting

The data analysis flow to extract breast-height-diameters for selective cutting is divided into four consecutive phases. The first phase is projecting the raw point cloud to horizontal plane. The second phase is filtering the invalidation scanning data and extracting each trunk from the calibrated point cloud. The third phrase is determining the breast-height-diameters and center location of the trunks. The fourth phrase is storing the result and displaying the useful information on the computer realized by VC++ and MATLAB.

3.1. Getting the Scanning Data

In the plantation forest, laser beams reflect if they meet the trunks or other object. The distance values are provided every 0.25° from 40° to 140°, and a fan-shaped scan is made of the surrounding area. The number of distance values is 401. As the individual distance values are given out in sequence via the RS485 data cable, the angular position of every individual distance value can be allocated on the basis of the values' position in the data string [4].

Fig. 2. The laser scanning in the plantation forest.

In the experiment, by adjusting tripod, the height of the scanning plane is equal to about 1.3 meters from the ground, and the variation in the height of the scanning plane is assumed to be negligible in our experiment. The measurement range is limited to 8 m, which is not beyond the reachable workspace of the crane of the logging harvester and can echoing sufficient laser echo data from a single trunk.

The raw distance value of every scanning angular acquired directly from the laser scanner is l_i^{raw} where i=1 to 401, α and β are the roll and pitch angle acquired by MTi respectively.

Supposing vector $V_i = [l_i, \theta_i]$, where θ_i is the angular positions; l_i is the horizontal distance value between the laser reflecting point and the measuring base point, then, l_i can be calculated as following equation (1):

$$l_i = l_i^{\mathrm{raw}} \times \cos\alpha \times \cos\beta \quad (1)$$

After the scanning experiment in the plantation forest, the laser scanning measurement data forms point cloud in polar form shown in Fig. 3. The green line is the border of scanning plane and the red circle is the base point of the laser scanner. In Fig. 3, the areas behind the nearest trunk are blind, while, the harvester commonly works on the nearest trunk firstly during the logging operation, so the scanning blind areas can be negligible [4].

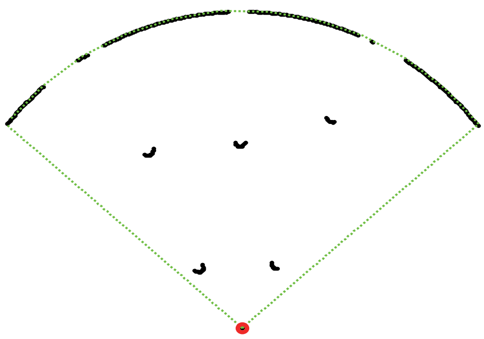

Fig. 3. The scanning point cloud.

3.2. Point Cloud Clustering

The measurement data is processed in increasing order of the bearing angle from 40° to 140°. Supposing the l_i is the distance value of the i^{th} scanning point, then the difference equation of scanning points can be given as following:

$$l_i - l_{i-1} = \Delta l \quad (2)$$

Supposing $\Delta l_{\max}$ is the threshold for the allowed distance in distance inside a cluster, then using the difference equation (2), if $|\Delta l|$ is larger than $\Delta l_{\max}$, one of points i^{th} and i-1^{th} belongs to the cluster and the other one belongs to the background or other cluster. In our experiment, $\Delta l_{\max}$ is chosen as 0.2 m.

After clustering, five clusters (in blue circles) defined in rectangular form can be extracted from the point cloud as shown in Fig. 4.

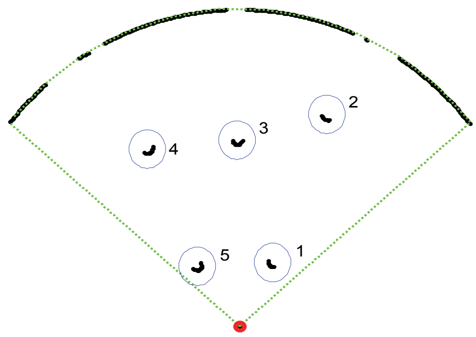

Fig. 4. The clustering result.

3.3. Filtering the Incorrect Data

In the forest, the laser beam may hit the uninterested things, branches or ground, and incorrect measurement data may exist in the point cloud, therefore, the filtering algorithms should be used to filter out the incorrect points or cluster from the point cloud, and accept only the trunk clusters. The filtering is performed for each cluster by testing it against following four criteria [4, 6]:

1) The minimum and maximum curvatures of the whole cluster;

2) The minimum value for the curvature of a single point cur_i;

$$cur_i = (l_{i+1} - l_i) - (l_i - l_{i-1}) = l_{i+1} - 2l_{i-1} + l_i \quad (3)$$

3) The greatest acceptable width of the cluster;

4) The smallest acceptable depth of the cluster.

3.4. Calculating the Breast-height-diameters and the Center Locations of the Trees [4]

The clusters in the point cloud can be used to calculate the breast-height-diameters and the center locations for the selective cutting.

After filtering and extracting the trunk clusters from the point cloud, the vector $V_i = [l_i, \theta_i]$ of the validated points can be transform to the vector $P_i = [p_i^x, p_i^y]$ defined in rectangular form.

Supposing that the matrix the $P = [P_1, P_2, \cdots P_m]^{\mathrm{T}}$ represents the position of every point in the truck cluster in rectangular form, m is the number of points in one cluster.

On the assumption that all cross sections of the standing trees are approximate standard circle, then the center location of the trunk is $O = (O_x, O_y)$ and the breast-height-diameters of the trunk is D, then, the vector $P_i = [p_i^x, p_i^y]$ satisfies:

$$\begin{aligned}&(p_i^x - O_x)^2 + (p_i^y - O_y)^2 = (D/2)^2 \\ &\Rightarrow 2p_i^x O_x + 2p_i^y O_y + [D^2/4 - (O_x)^2 - (O_y)^2] \\ &= (p_i^x)^2 + (p_i^y)^2\end{aligned} \quad (4)$$

In this paper, the PRP conjugate gradient algorithm method is used to fit a circle from the vector $\boldsymbol{P}_i$ in a trunk cluster and to estimate the parameters of every trunk. In order to use the PRP conjugate gradient algorithm, supposing, the equation (4) is transformed as following [4]:

$$\begin{gathered} a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 = b_i \\ \boldsymbol{x} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} O_x \\ O_y \\ D^2/4 - (O_x)^2 - (O_y)^2 \end{bmatrix} \boldsymbol{a_i} = \begin{bmatrix} a_{i1} \\ a_{i2} \\ a_{i3} \end{bmatrix} = \begin{bmatrix} 2p_i^x \\ 2p_i^y \\ 1 \end{bmatrix}, \\ b_i = (p_i^x)^2 + (p_i^y)^2 \end{gathered} \quad (5)$$

where $\boldsymbol{x}$ is the unknown vector.

Then the points in one cluster can form the set of linear algebraic equation with constant coefficients as following equation (6):

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + a_{13}x_3 = b_1 \\ a_{21}x_1 + a_{22}x_2 + a_{23}x_3 = b_2 \\ \vdots \\ a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 = b_m \end{cases} \quad (6)$$

The equation (6) can be written in a vector-matrix form as following equation (7):

$$A\boldsymbol{x} = \boldsymbol{b}, \quad (7)$$

where it is assumed that $A \in \Re^{m\times 3}$, and $\boldsymbol{x} \in \Re^{3\times 1}, \boldsymbol{b} \in \Re^{m\times 1}$.

$$\begin{gathered} A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & a_{m3} \end{bmatrix} \\ \boldsymbol{x} = [x_1, x_2, x_3]^{\mathrm{T}} \quad \boldsymbol{b} = [b_1, b_2, \cdots, b_m]^{\mathrm{T}}, \end{gathered} \quad (8)$$

For $m > 3$, equation (7) is referred to as being over-determined (more equations than unknowns). In this paper, the PRP conjugate gradient algorithm is used to solve equation (7).

The PRP conjugate gradient algorithm is a real time and online neuro-computing approach for solving system of linear algebraic equations and can achieve better performance than Fletcher-Reeves (F-R) conjugate gradient algorithm.

The PRP conjugate gradient algorithm is different from the FR conjugate gradient algorithm on the search direction calculation method, and can be given as following [9-12]:

Supposing $\boldsymbol{x}_k$ is the discrete-time iterative solution of equation (7), k is the discrete-time index, then, the solution error for solving $A\boldsymbol{x} = \boldsymbol{b}$ is given by:

$$\boldsymbol{e} = A\boldsymbol{x}_k - \boldsymbol{b} \quad (9)$$

The PRP algorithm can be incorporated into the discrete-time learning rule to derive an update expression for the iterate $\boldsymbol{x}_k$, the update of the solution is given by

$$\boldsymbol{x_{k+1}} = \boldsymbol{x_k} + \alpha_k d_k,$$

where:

$$\alpha_k = \frac{-d_k^{\mathrm{T}} g_k}{d_k^{\mathrm{T}} A^{\mathrm{T}} A d_k}$$

The vector $\boldsymbol{d_k}$ is the current direction vector, and $\varepsilon(\bullet)$ is the object function to be determined, and is given by

$$\varepsilon(x) = \frac{1}{2}\|\boldsymbol{e}\|_2^2 = \frac{1}{2}\boldsymbol{e}^{\mathrm{T}}\boldsymbol{e}$$

Therefore, the PRP conjugate gradient algorithm for solving equation (7) is summarized in the following steps [4, 12]:

- Step1: Set initial condition $\boldsymbol{x}_0$.
- Step2: Compute $g_k|_{k=0} = g_0 = A^T A\boldsymbol{x}_0 - A^T b$.
- Step3: Set $d_0 = -g_0$.
- Step4: Compute $\boldsymbol{x_{k+1}} = \boldsymbol{x_k} + \alpha_k d_k$, where $\alpha_k = -g_k^T d_k / (d_k^T A^T A d_k)$
- Step5: Compute $g_{k+1} = A^T A\boldsymbol{x_{k+1}} - A^T b$.
- Step6: Compute $d_{k+1} = -g_{k+1} + \beta_k d_k$, where $\beta_k = \frac{g_{k+1}{}^T [g_{k+1} - g_k]}{g_k{}^T g_k}$.
- Step7: If $k < k_{\max}$ go to step 4.
- Step8: Continue until convergence is achieved; termination criterion could be $\|d_k\| < \varepsilon$ (where ε is an appropriate predetermined small number) and $k > k_{\max}$.

Where $k_{\max}$ is the maximum number of iteration. In our experiment, $k_{\max}$ is set to 1000 and the initial condition $\boldsymbol{x} = [0,0,0]^{\mathrm{T}}$, consequently, faster convergence can be expected.

After solving the unknown vector $\boldsymbol{x}$, the center location of the trunk $O = (O_x, O_y)$ and the breast-height-diameters of the trunk D can be calculated as following equation (10):

$$O_x = x_1; \quad O_y = x_2; \quad D = 2\sqrt{x_1^2 + x_2^2 + x_3} \quad (10)$$

4. Experiment Results

The result of the calculation is given as the following Fig. 5. There are five blue circles which are the fitting result of the point cloud of trees (tree 1st to tree 5th) at the breast height, and the centres of the trees are marked by the red circles.

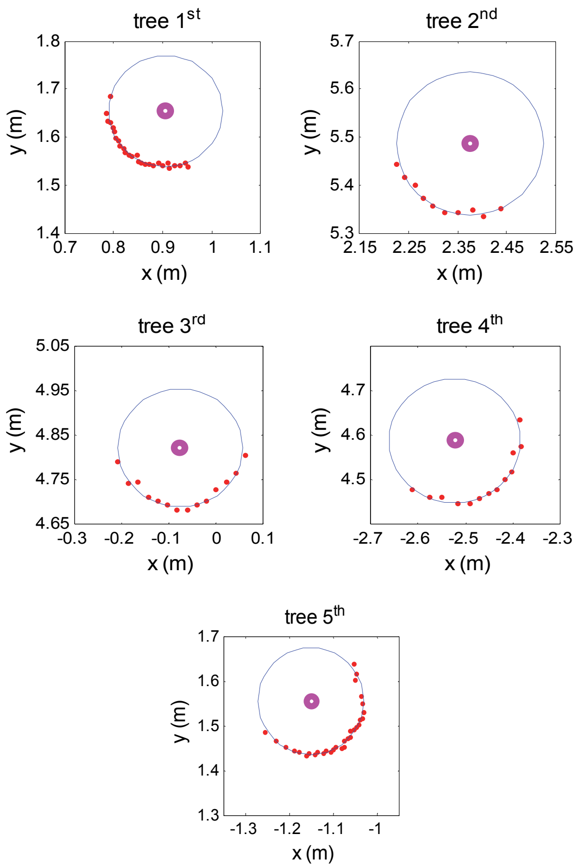

Fig. 5. The result of the calculation.

Supposing the measuring base point is the origin of the rectangular form, the column 2nd and 4th of the Table 1 gives the manual measurement value of and diameters and the central locations of the trees, which are acquired by the vernier and range finder respectively. The column 3th and 5th of the Table 1 gives the calculation result via the PRP algorithm used in this paper.

As shown in Table 1, using laser scanning and PRP algorithm, the maxim error on the breast-height-diameters and the center locations are 2.3 cm and (12.4, 11.4) cm, and the characteristics of the calculation meet the requirement on the accuracy for the selective cutting operation.

Table 1. The parameters of the trees.

No.	Diameter (cm)		Center location (O_x, O_y) (cm)	
	Manual	PRP algorithm	Manual	PRP algorithm
1	22.7	23.2	(88.4, 166.3)	(90.6, 165.4)
2	27.6	29.9	(250.0, 560.1)	(237.6, 548.7)
3	27.2	26.3	(-2.0, 476.5)	(-7.6, 482.2)
4	28.5	27.7	(-245.7,465.2)	(-252.3, 458.8)
5	24.3	24.0	(-116.9,152.5)	(-115.1, 155.5)

The calculation result is shown in the human-computer software as Fig. 6, which is coded by the mixed programming of VC++ and MATLAB. In this software, the parameters of the trees for selective cutting, such as breast-height-diameters, the center locations and distances between the adjunct trees can be calculated and shown in real time.

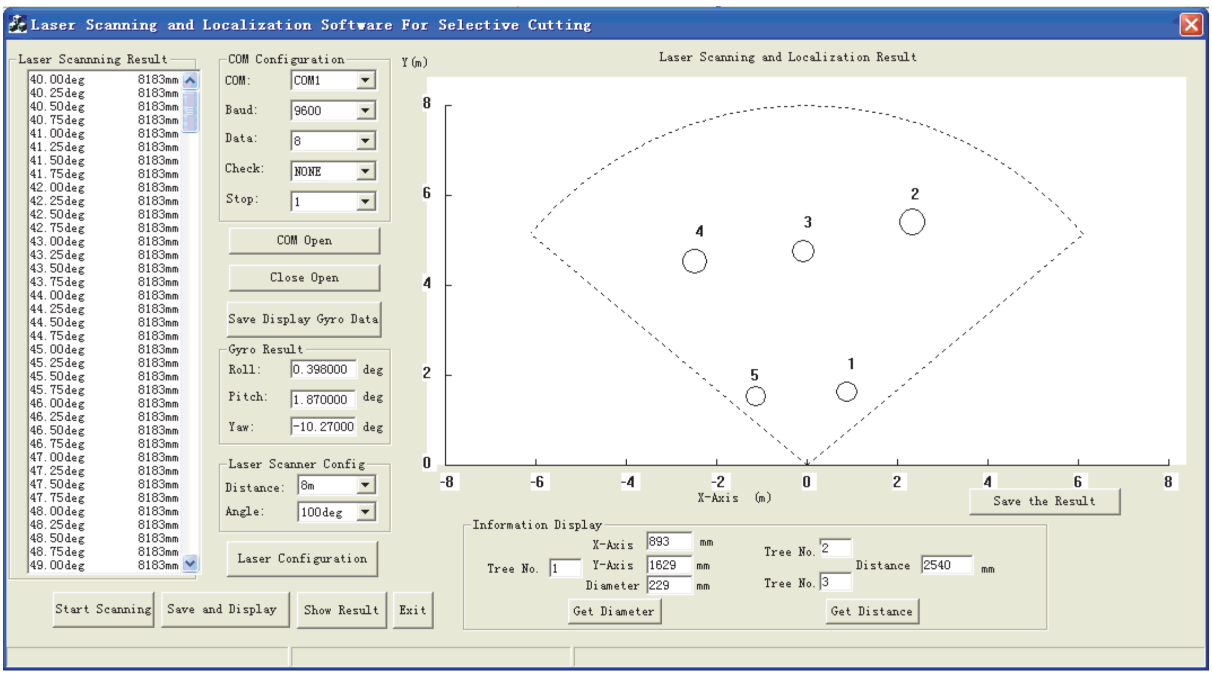

Fig. 6. The interface of the software.

5. Conclusions

In this paper, the point cloud for the standing trees is collected with a 2D laser scanner. The cluster and filtering process are used to classify trees from the point cloud. The breast-height-diameters and positions of the trees are calculated by the PRP algorithm. The accuracy meets the requirement of the selective cutting operation. The laser scanner and inertial measurement system presented in this paper can be mounted on the outer boom of the crane to determine the location of the trunk near the harvesting head to realize automatically selective cutting of the logging harvest in forest.

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