Research Paper

Journal of JSAM 69(1): 59~67, 2007

Development of a Calibration Method for 2-dimensional Laser Scanner Mounted on an Automated Vehicle

Oscar C. BARAWID Jr.*1, Kazunobu ISHII*2, Noboru NOGUCHI*2

Abstract

The objective of this study is to develop a calibration method to get the exact position of the 2-dimensional laser scanner mounted at the front of an automated vehicle from a reference coordinate system before the automatic navigation in an orchard application. The research is limited only in calibrating a 2-dimensional laser scanner that gathers distance and angle data of the objects in front of it. The methods used in this research are Hough transform, Euler rotation theorem and LSM (least squares method). The calibration results identified the exact attachment position of the laser scanner with respect to the vehicle coordinates. Finally, field test runs for autonomous guidance with developed calibration was conducted to confirm the travel accuracy improvement. The accuracy of both lateral and heading error for calibrated sensor was higher than run of subjected calibration.

[Keywords] 2-dimensional laser scanner, robot tractor, Hough transform, lsm (least squares method)

I Introduction

Calibration of any sensors attached onto the vehicle or equipment is necessary to obtain environment information. After the installation of the sensor, it is necessary to check if the sensor is aligned or centered properly with respect to the reference axes. For sensors such as a video cameras, a laser range finder, an ultrasonic sensor, a 2-d laser scanner and a GPS (global positioning system) etc., the position and orientation of the sensor affects the geometric interpretation of its measurements (Pless et al., 2003).

LMS (laser measurement sensors) are a popular method for acquiring optical measurement data of the objects in any position due to their accuracy. In order to maximize the range accuracy, a proper calibration method has to be applied. However, calibration of sensors is not an easy task. The determination of the fitting algorithm method alone is time-consuming not to mention the choice of the appropriate auxiliary equipment that would ensure ideal data. One thing to consider is the cost of engineering equipment to be used in calibration. Engineering costs arise from both expensive components and difficult calibration requirements (Davis et al., 2001). A laser range scanner designed for minimum calibration complexity (Davis et al., 2001) used a laser triangulation scanners method for acquiring three-dimensional geometry of the objects due to their accuracy and robustness. In the said method, two-camera range scanner design was utilized to minimize calibration complexity and cost, and eliminates all actuated components from the calibrated geometry. In this research essential equipment were used to calibrate the laser scanner such as the RTK-GPS (real-time kinematic global positioning system), a FOG (fiber optic gyroscope), and a total station. Nowadays, these sensors are getting inexpensive due to popular demand and due to its efficiency in yielding optimal calibration results. Usually, the choice of the engineering equipment to use for the scanner calibration is subject on the institutions' availability of the resources.

The potential applications of laser scanners are numerous, and cross several sectors of the industry construction, large-scale manufacturing, remote sensing, agricultural production, national defense, etc. (Cheok et al., 2002). When the sensors are used without the calibration, the results in accuracy evaluation may increase or decrease. The effect of the inaccuracy of the evaluated results makes the developed system inefficient, because it is not the actual evaluated accuracy. Therefore, calibration of the attachment position of any sensors is very essential before application for such purpose.

In this research, the developed method for the calibration of laser scanner attachment position did not utilize a calibration platform compared to other methods. Posture estimation for autonomous weed-

*1 JSAM Student Member, Graduate School of Agriculture, Hokkaido University, Kita 9, Nishi 9, Kita-Ku, Sapporo, 060-8589, Japan, TEL 011-706-3847

*2 JSAM Member, Graduate School of Agriculture, Hokkaido University, Kita 9, Nishi 9, Kita-Ku, Sapporo, 060-8589, Japan, TEL 011-706-3847 ; e-mail of corresponding author : noguchi@bpe.agr.hokudai.ac.jp

ing robots navigation in nursery tree plantations (Khot et al., 2005) used a calibration platform to calibrate the attachment position of the sensor. This calibration platform consists of a fabricated steel track where the calibration method was performed for the prototype robot vehicle. The advantage of using prototype robot vehicle is that the calibration platform model is not big enough to construct. But in this research, it is not advisable to make a calibration platform because the robot tractor is too big and the construction cost is expensive. A new calibration method was developed and introduced in this research using a unique technique. The unique technique used in this research is the use of the perpendicular wall. This perpendicular wall served as the reference line for the laser scanner calibration.

The main thrust of the study is to develop a calibration method to obtain the actual laser scanner attachment position which will soon be used to correct the data outputs in an autonomous navigation of the robot tractor. The attachment position of the laser scanner is called offset position values. These offset position values of the laser scanner are important to know because it will determine if the sensor attachment is properly aligned or centered with respect to reference axes. In addition, it will affect the system accuracy evaluation due to inappropriate installation.

The developed calibration method for obtaining the laser scanner attachment position used three essential sensors, FOG which served as the heading sensor. The function is to obtain the relative heading direction of the robot tractor. A RTK-GPS receiver was used as the positioning sensor to get the absolute position of the robot tractor. And, a total station which is basically a transit (surveying instrument) used to obtain the relative position (x, y and z axes) of the perpendicular wall. The perpendicular wall is wall perpendicular to the GPS antenna which is mounted on the top of the cabin of the robot tractors' center of gravity and the laser scanner which is attached in the front of the robot tractor, served as the reference line to obtain the exact attachment position of the laser scanner with respect to the reference axes.

The methods used in this research were Hough transform to recognize the perpendicular wall as straight line, Euler rotation theorem to transform the perpendicular wall relative coordinates into UTM (universal transverse Mercator) coordinates, LSM (least square method) to get the scanning offset error of the laser scanner which is the laser scanner exact attachment position.

II Research components

This research used a 56-kW standard tractor, which was modified into a robot tractor. The robot tractor controlled steering, transmission (forward, neutral and backward), PTO (power take-off), engine speed, brake system and three-point hitches (up and down). The LMS 291 is the laser scanner to be calibrated, (SICK AG, Division Auto Indent). It was attached in the front of the robot tractor as shown in Fig. 1. The sensor is NCMS (non-contact measurement system), which can scan its surrounding in two-dimensional measurements, the object distance and the object angle with respect to the direction of transmission. Figure 2a shows the LMS 291 and its direction of transmission. The figure shows the scanning angle direction is counterclockwise and area monitoring which means that an infringement of a field, e.g. by an object, leads to a switching signal at an output. The sensor was set to 80 m distance range, 1 deg angle resolution and 13 ms response time shown in Fig. 2b. It has a distance error of ±5 cm. The advantages of using the laser scanner as the navigation sensor are rapid scanning times thus measurement objects can move at high speeds, no special target-object reflective properties necessary, no reflectors and no marking of the measurement objects necessary, backgrounds and surroundings do not have any influence on the measurements, measurement data is available in real time and can be used for further processing and completely weatherproof variants. Table 1 shows the LMS 291 technical specifications.

The three essential sensors used to calibrate the laser scanner were the RTK-GPS receiver (MS 750 dual frequency RTK receiver, Trimble Navigation Ltd.). The MS 750 GPS receiver was preferred to use in this research because it has the highest level of accuracy and response available to receive information and it is specially designed to allow the easy integration of reliable-level positions to any guidance or control application. In the experiment run, the RTK-GPS receiver input was set to 1 Hz and the output was set to 10 Hz. It has a positioning accuracy of ±2 cm. The FOG,

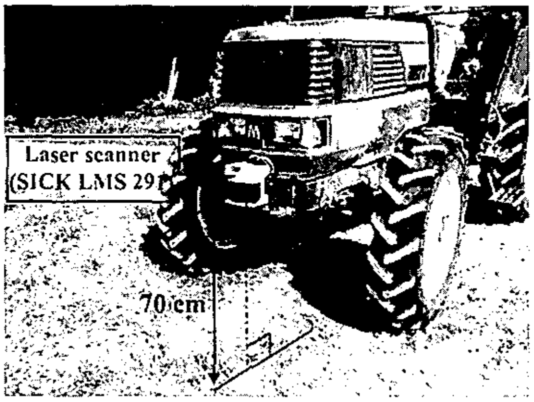
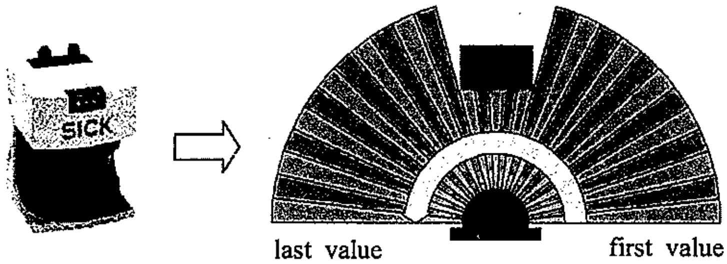
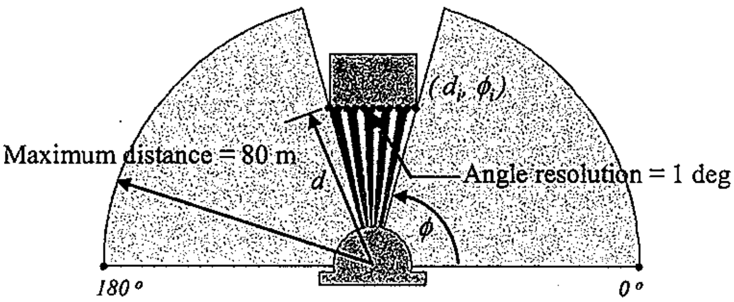


Fig. 1 Laser scanner attachment position on front of the robot tractor



(a) Laser measurement scanner (LMS 291) scanning angle direction of transmission



(b) Laser scanner diagram with angle and distance range set to 180 deg and 80 m, respectively

Fig. 2 Measurement principle of laser scanner

Table 1 Technical specification of the LMS 291 (laser measurement system)

Descriptions	*Measurements*
	General
Range	max. of 80 [m]
Angular resolution	0.25/0.5/1 [deg]
Scanning angle	180 [deg]
Response time	53/26/13 [ms]
Measurement resolution	10 [mm]
System error	typ. +/−35 [mm] (mm-mode), range 1......20 m typ. +/−5 [cm] (cm-mode), range 1......20 m
	Electrical
Data interface	RS 232/RS 422 (configurable)
Transfer rate	9.6/19.2/38.4/500 [kbaud]
Supply voltage (scanner-elctronics)	24 V DC +/−15% (max. 500 mV ripple)
Power consumption	approx. 20 [W]plus heating with approx. 140 W
Operating ambient temperature	0.... +50 [℃]
	Mechanical
Weight	approx. 4.5 [kg]
Vibration fatigue limit	10.....150 Hz, amplitude 0.35 mm or 5 g single impact
Dimension (LxWxH)	156×137×210 [mm]

(JG-35FD, Japan Aviation Electronics Industry, Ltd.) was used as the heading sensor. This sensor obtained the heading angle necessary for the calibration method during the experiment run. The sensor drift angle accuracy is ±0.5 deg/hour. And, the total station (APL-1, TOPCON Ltd.) used as the positioning sensor to obtain the relative position (x, y, and z axes) of the perpendicular wall with an accuracy of ±3 mm for fine mode and ±10 mm for course mode. The total station was set to fine mode setting. All sensors are connected to the laptop PC using RS-232 cable. Figure 3 shows the schematic diagram of the research components.

III Methods

1. Hough transform algorithm

(1) Hough transform sampling

The Hough transform used in this research as the algorithm to recognize the perpendicular wall as a straight line. It was patented by Paul V.C. Hough in 1962. It used for linear or circular detection. The main advantage of using Hough transform compared to commonly used method like least squared error method of fitting lines to image data, is that even if group points varies to some extent, asking for a straight line is possible. Also, processing is collectively possible even when there are two or more straight lines in the image data. The point which has the majority of intersection served as the line equation. The disadvantage, on the other hand, is that in order to plot curves (*i.e. sinusoids*) for every observing point (x_i, y_i) in Cartesian image space to r-θ polar Hough parameter space, the load of computational complexity is large.

Consider the normal Cartesian equation of a straight line, which is generally on an x-y plane,

$$y=mx+c \qquad (1)$$

where m is the slope and c is the y-intercept. Consider some points of the image data where a straight line can be obtained from its edge. Transform the points into r- normal representation of a line in Hough space (only points where the line pass through) which was shown in Fig. 4a. The shortest distance from the origin can be obtained equivalent to Eqn (2) (Gonzales and Wood et al., 1993).

$$r=x\cos\theta+y\sin\theta \qquad (2)$$

In Eqn (2), the line is defined in terms of r and θ, where r is shortest distance from origin to line and θ is the orientation angle with respect to the x-axis. The range of angle θ is $\pm$90 deg, measured with respect to the x axis. For any point (x, y) on this line, r and θ are constant. Equation (2) can be considered a relation between the coordinates (x, y) of some points in the edge image, and the value of the parameters (r-θ) which defines the equation of the line. The points in Cartesian space correspond to a sine wave r-θ polar in Hough parameter space shown in Fig. 4b. In Fig. 4b, the point where the majority of these sinusoids intersect serve as the equation of the line. For example, the value of distance r is equivalent to 6.06 units and the angle θ is equivalent to 40 deg. The equation of the line is $y=-1.19x+9.4$.

(2) Perpendicular wall recognition as a straight line using Hough transform

Applying the Hough transform to the data obtained by the laser scanner during the calibration experiment run, the perpendicular wall was recognized as a straight line. The perpendicular wall will serve as the base line for the laser scanner calibration.

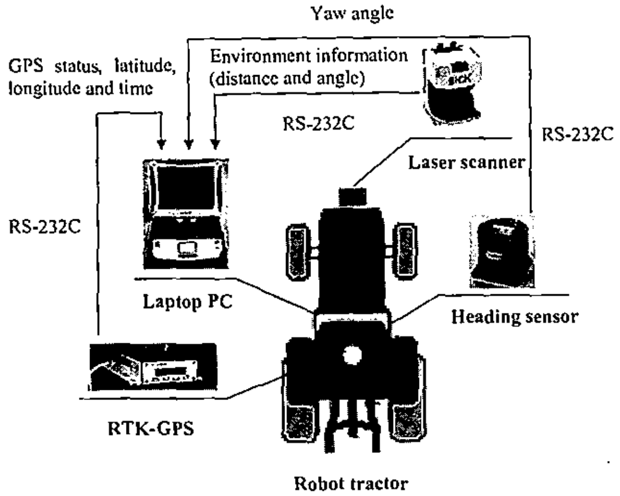
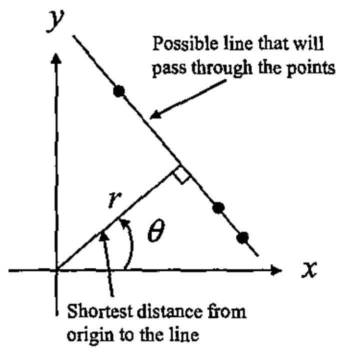
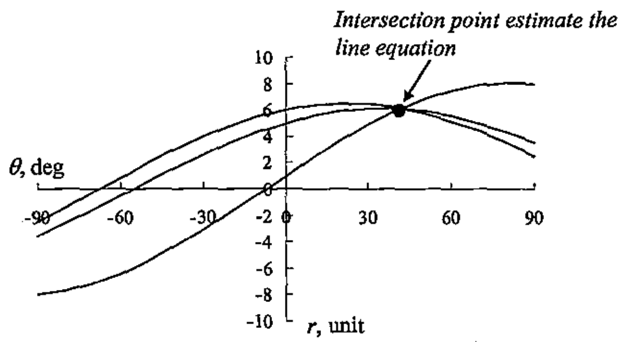


Fig. 3 Schematic diagram of the research components used in the calibration method of the laser scanner



(a) r-θ space normal representation of a line in Hough transform



(b) Points transform to sinusoids in r-θ space

Fig. 4 Basics of Hough transform

Figure 5 shows the outline of the perpendicular wall recognition using the laser scanner. In the figure, the points were the components of the perpendicular wall scanned by the laser scanner. Using r-θ parameterization space, a point in Cartesian space (x_i, y_i) corresponds in the r-θ space ; Eqn (2) can be written in the form of Eqn (3) ;

$$r=d_i\cos(\phi_i-\theta) \quad (0\leq i\leq 180,\ 0\leq\theta\leq 180) \tag{3}$$

In Eqn (3), r is the shortest distance between the laser scanner and the perpendicular wall, d_i is the measured distance between the perpendicular wall and the laser scanner, ϕ_i is the relative angle of the perpendicular wall with respect to the laser scanner detection, and θ is the angle between the perpendicular wall and the laser scanner.

The main advantage of the r-θ is that quantization is relatively easy because not all the parameter space needs to be considered. Looking at Fig. 4b, the sinusoids all have the same period, and therefore ϕ_i can be limited to any angle range depending on the application without losing its generality. In this research, the ϕ_i limit was $0\leq i\leq$ and $0\leq\theta\leq 180$.

Figure 6a shows the actual captured points of the laser scanner on the surface of the perpendicular wall. The black points represent the wall and the black line corresponds to the estimated line. Transforming the data obtained by the laser scanner into a r-θ parameterization space shown in Fig. 6b using the Hough transform, a cluster of intersections were intersected. The majority of intersections served as the equation of a line of the perpendicular wall.

2. Calibration procedure for 2-d laser scanner

(1) Transformation of local coordinates to UTM coordinates

The perpendicular wall relative position (x, y and z axes) was measured by the total station (surveying instrument) and then the starting edge point absolute position was measured by RTK-GPS. After determining the perpendicular wall as a straight line using the laser scanner, next is to transform the relative position into absolute position by using Euler rotation theorem. In this method, the rotation is about the z-axis in counterclockwise direction. Eqn (4) shows the rotation matrix in z-axis.

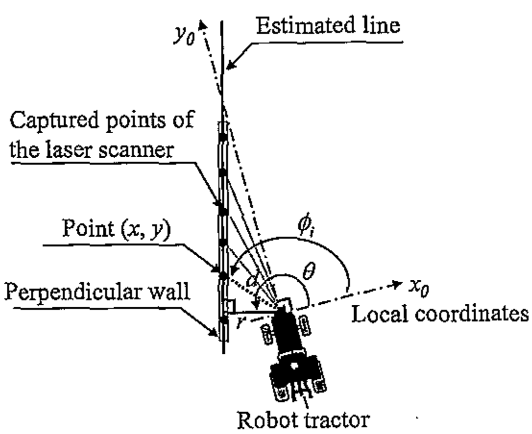


Fig. 5 An outline on how to recognize the perpendicular wall as straight line using the Hough transform as the algorithm

$$R_{z(\rho)}=\begin{bmatrix}\cos\rho & -\sin\rho\\ \sin\rho & \cos\rho\end{bmatrix} \tag{4}$$

In the equation, ρ is the rotation angle in deg, can be obtained in the perpendicular wall angle in the UTM coordinates. Eqn (5) calculated absolute position of the perpendicular wall.

$$\begin{bmatrix}E_s\\ N_s\end{bmatrix}=R_{z(\rho)}\begin{bmatrix}x_s\\ y_s\end{bmatrix}+\begin{bmatrix}E_o\\ N_o\end{bmatrix} \tag{5}$$

Where the (E_s, N_s) is the transformed position in UTM coordinates, (x_s, y_s) is the relative position of the perpendicular wall taken by the total station, and (E_o, N_o) is the starting edge point of the perpendicular wall.

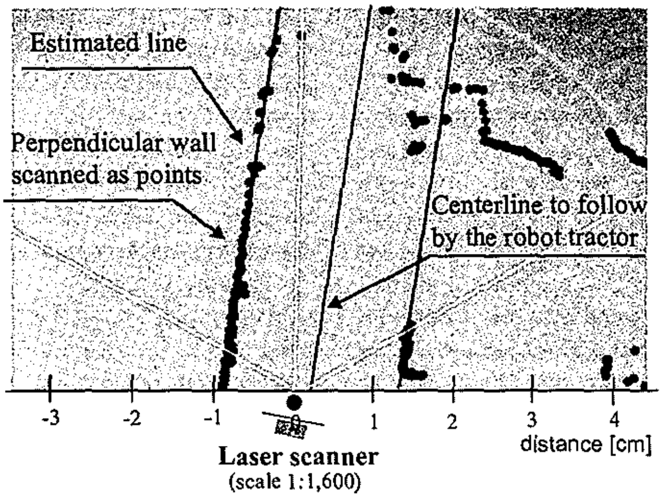
(2) Determination of the offset position of the laser scanner using LSM

The next method to be explained is the determination of the offset position values of the laser scanner attached on the front of the robot tractor. The offset position values are between the laser scanner and the GPS antenna which was shown in Fig. 7. In the figure, a and b are the laser scanner offset values (x and y axes) in m and the δ is the offset angle of the laser scanner in deg at the vehicle coordinate system, respectively. The center point of the laser scanner from perpendicular wall is denoted by E in m. The value of E can be computed from the data obtained by the laser scanner in distance (d) and angle (θ) using Hough transform using Eqn (3). The values of the distance (E) depend on the equation of the perpendicular wall obtained previously by the laser scanner recognition as a straight line. The distance from the GPS antenna to the perpendicular wall is denoted by D in m. To solve the distance (D), the straight line equation of the perpendicular wall is needed in UTM coordinates by using Eqn (6), where α, β, and c are numerical values (real numbers), and x and y are variables.

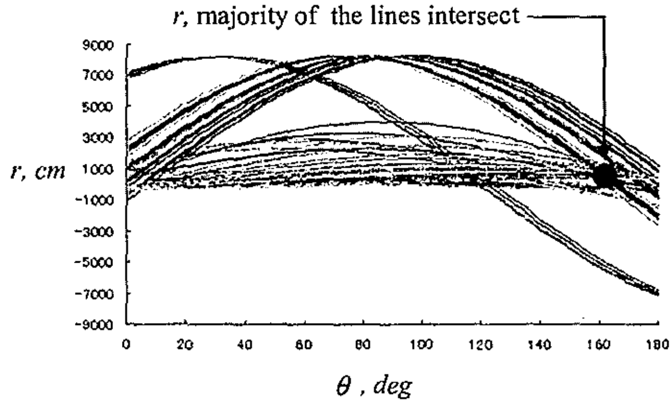
$$\alpha x+\beta y+c=0 \tag{6}$$

Using the perpendicular distance relation between the perpendicular wall and GPS antenna the distance (D) can be solved by Eqn (7), where point (x_{GPS}, y_{GPS}) is the location of the GPS antenna. The values of x_{GPS} and y_{GPS} were obtained from the GPS data.

$$D=\frac{abs|\alpha x_{GPS}+\beta y_{GPS}+c|}{\sqrt{\alpha^2+\beta^2}} \tag{7}$$



(a) Actual captured points by the laser scanner in a computer window



(b) Illustration of the captured points of the laser scanner transform to sinusoids in r-θ space

Fig. 6 Transformation of the captured points using Hough transform

The angle (ϕ) between the perpendicular wall and vehicle coordinate system is given by

$$\phi=\eta-\upsilon \tag{8}$$

where η is the angle of the vehicle direction in deg with respect to the UTM coordinate. The value of η was come from the heading sensor installed inside the robot tractor cabin. And, υ is the angle of the perpendicular wall in deg with respect to the UTM coordinate. The perpendicular wall line equation in UTM coordinate system was determined by measuring the wall edge using the GPS. The angle υ can be obtained from the wall line equation. The equation for solving the offset angle δ of the laser scanner is shown in Eqn (9).

$$\delta=\kappa-\phi \tag{9}$$

Using the Hough transform, κ is the angle between the laser scanner's exact position in deg and the perpendicular wall, computed from the data obtained by the laser scanner during the calibration experiment run.

Since line (E) and line (D) are parallel, the position of the laser scanner can be calculated using Eqn (10) in vehicle's coordinate system.

$$a\cos\phi+b\sin\phi=E-D \tag{10}$$

However, $E-D$ values have measurement errors. Through using the least squares method, the minimum errors were obtained. The error was acquired by i in a straight line in n value of observation as

$$a\cos\phi_i+b\sin\phi_i+D_i-E_i=0 \tag{11}$$

Assigning the F_i as

$$F_i=D_i-E_i \tag{12}$$

Using LSM, the minimum error ε_i can be calculated in

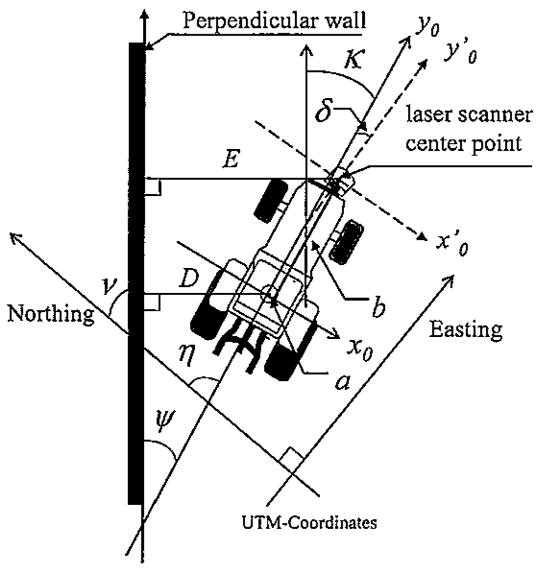


Fig. 7 Calibration method outline using a perpendicular wall as the reference line for getting the laser scanner exact position

Eqn (13).

$$\varepsilon_i^2 = (a\cos\phi_i + b\sin\phi_i + F_i)^2 \quad (13)$$

Solving for the least square estimates by summing of all observation data :

$$S_\varepsilon = \sum_{i=0}^{n} \varepsilon_i^2 \quad (14)$$

Using partial derivatives, the minimum error can be calculated in Eqns (15) and (16) which are set to 0.

$$\frac{\partial S_\varepsilon}{\partial a} = \sum_{i=0}^{n} (2a\cos^2\phi_i + 2b\cos\phi_i\sin\phi_i + 2\cos\phi_i F_i) = 0 \quad (15)$$

$$\frac{\partial S_\varepsilon}{\partial b} = \sum_{i=0}^{n} (2a\cos\phi_i\sin\phi_i + 2b\sin^2\phi_i + 2\sin\phi_i F_i) = 0 \quad (16)$$

The values of the offset position of the laser scanner were $a = -0.056$ m, $b = 2.57$ m and $\delta = 2.8$ deg from the vehicle coordinates. The calibration results were obtained in a single experiment only. Different runs were conducted in this single experiment with different heading directions, the obtained laser scanner offset position values were the same.

IV Results and discussion

1. Determined offset position values of the laser scanner

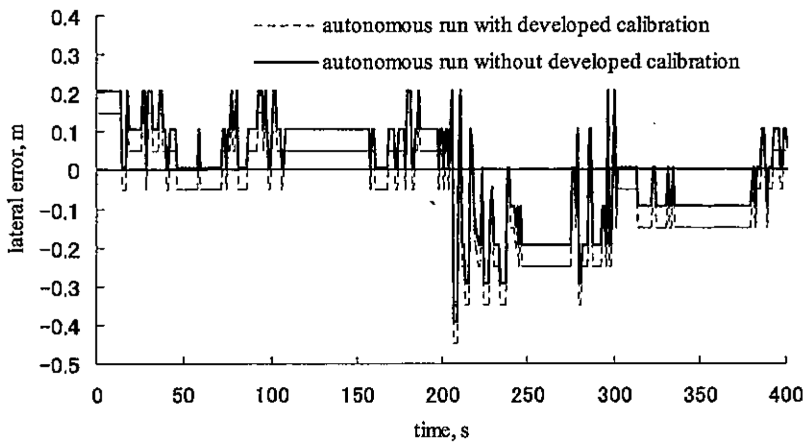
To obtain the offset position values of the laser scanner different algorithms-- Hough transform was used to determine the line equation of the perpendicular wall, Euler rotation theorem was used to transform the position of the wall measured by laser scanner into the UTM coordinate system, and LSM was used to obtain the offset values of the laser scanner (*a*, *b*, and δ). A unique technique was also used to obtain the offset position values. This technique was the utilization of the perpendicular wall as the reference line to develop calibration method for the laser scanner attachment position. The developed calibration method determined the offset position values of the laser scanner as $a = -0.056$ m, $b = 2.57$ m and $\delta = 2.8$ deg. These values were the exact location on the robot tractor attachment position and proved that the attachment position of the laser scanner was not properly aligned or centered with the reference coordinate. This condition justifies the need for the calibration of the laser scanner and it is very important to implement because of the effect on the evaluation accuracy on any system. In this research, the offset position values will be used in the accuracy evaluation to correct the data obtained by the laser scanner in an autonomous navigation orchard application.

2. Evaluation of the autonomous run outputs with and without the developed calibration

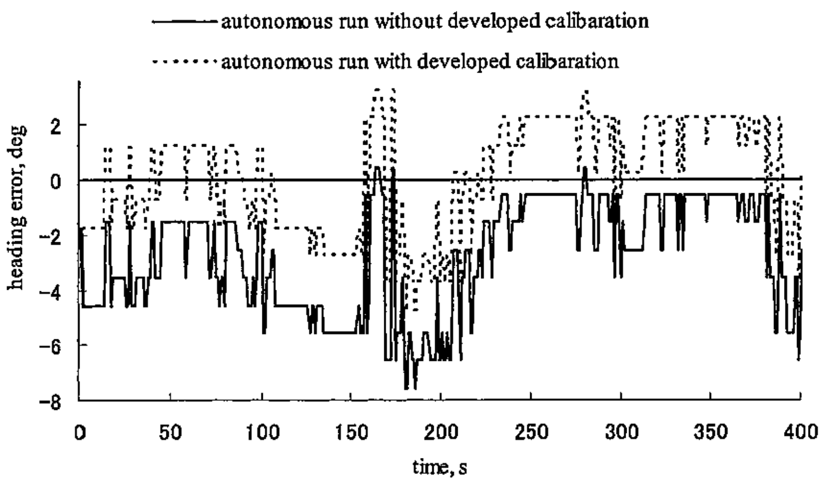
The laser scanner was installed in the front of the automated vehicle by the subjective conjecture that its direction was parallel to the reference axis. In order to see the effect of the presence or the absence of the laser scanner calibration in accuracy evaluation of the autonomous navigation, a series of autonomous runs were conducted. The experiment runs were conducted in the Hokkaido University, Sapporo, Japan. The selected test site was approximately 40 m by 3 m in length and width. The area which resembled an orchard was spanned with trees in two vertical rows. Figure 8 shows the accuracy evaluation of autonomous navigation with developed calibration and without developed calibration. In the figure, the black line represents the data without developed calibration and the broken line represents the data with developed calibration. This research shows the effect of not calibrating the laser scanner was that the accuracy errors tend to increase and the subjective conjecture calibration is not enough to do in attachment position of the any sensor. The RMSs (root mean squares) of lateral and heading mean errors of the autonomous run using the developed method were relatively smaller than those using subjective calibration. Table 2 shows the RMSs of the lateral and heading errors of the autonomous run with and without the developed calibration. Also, the data that was calibrated by the developed method were the actual data taken by the laser scanner because it was aligned with the reference coordinate axes of the robot tractor.

V Conclusion

The research developed an attachment calibration method for a 2-d laser scanner attached on the front of the robot tractor before the orchard autonomous application. The developed calibration method deter-



(a) Lateral error in autonomous run



(b) Heading error in autonomous run

Fig. 8 Comparison of lateral and heading errors with and without the developed calibration

Table 2 Evaluated accuracy results of the autonomous run in orchard application with and without the developed calibration

	Root mean squares (RMS) *with developed calibration*	*without developed calibration*
lateral error, m	0.19	0.22
heading error, deg	2.3	3.9

mined the position of the laser scanner in robot tractor coordinates using the reference coordinate. The reference coordinate was GPS antenna location. Hough transform recognized the perpendicular wall as a straight line and also obtained the distance between the perpendicular wall and the laser scanner center point, Euler rotation theorem transformed the perpendicular wall relative position to UTM coordinates, and LSM determined the minimum measurement errors in the laser scanner data acquisition which were the offset position values. And also, the utilization of the perpendicular wall was the technique help in determining the attachment position of the laser scanner. The offset position values of the laser scanner were $a=-0.056$ m, $b=2.57$ m and $\delta=2.8$ deg from the vehicle coordinates. The developed calibration method was used to correct data measured by laser scanner in the autonomous run in the area like orchard application.

References

Ahamed, T., Takigawa, T., Koike, M., Honma, T., Hasegawa, H., Zhang, Q., 2006. Navigation using a laser range finder for autonomous tractor (Part 1). Journal of JSAM, 68 (1), 77-86.

Ahamed, T., Takigawa, T., Koike, M., Honma, T., Hasegawa, H., Zhang, Q., 2006. Navigation using a laser range finder for autonomous tractor (Part 2). Journal of JSAM, 68 (1), 78-86.

Davis, J., Chen, X., 2001. A laser range scanner designed for minimum calibration complexity. Proceedings of the Third International Conference on 3D Digital Imaging and Modeling.

Downie, N., Heath, R., 1984. Basic statistical method. Harper & Row, Publishers, Inc., New York.

Gonzales, C., Woods, E., 1993. Digital Image Processing. Addison-Wesley Publishing, USA.

Kise, M., Noguchi, N., Ishii, K., Terao, H., 2001. Development of the agricultural autonomous tractor with an RTK-GPS and FOG. Proceedings of the Fourth IFAC Symposium on Intelligent Autonomous Vehicle, 103-108.

Khot, L., Tang, L., Blackmore, S., Norremark, M., 2005. Posture estimation for autonomous weeding robots navigation in nursery tree plantations. Proceedings of the ASAE Annual Meeting. Paper number 053092.

Mizushima, A., Noguchi, N., Ishii, K., 2004. Automatic navigation of agricultural vehicle using low cost attitude sensor. Proceedings of the Automation Technology for Off-Road Equipment Conference, 98-106.

Pless, P., Zhang, Q., 2003. Extrinsic auto-calibration of a camera and laser range finder. Department of Computer Science and Engineering, Washington University, St. Louis.

Ye, C., Borenstein, J., 2002. Characterization of a 2-d laser scanner for mobile robot obstacle negotiation. Proceedings of the IEEE International Conference on Robotics and automation. 2512-2518.

Zhang, L., Ghosh, B., 2000. Line segment based map building and localization using 2D laser rangefinder. Proceedings of the IEEE International Conference on Robotics and Automation. 2538-2543.

(Received : 25. May. 2006 • Question time limit : 31. March. 2007)

「研究論文」

自律走行車両に搭載した2次元レーザスキャナのキャリブレーション法の開発

バラウィッド オスカー ジュニア*1・石井一暢*2・野口 伸*2

要　旨

本研究は果樹園のような環境で自動走行させるために，自動走行車両に搭載した2次元レーザスキャナの正確な取付位置を取得できるセンサキャリブレーション法の開発を目的とした。センサ前方に存在する対象物までの距離と角度を出力できるレーザスキャナについて航法センサとしてのキャリブレーション法を検討した。開発したキャリブレーション法はハフ変換，回転座標変換，最小二乗法を組み合わせたものである。開発したキャリブレーションを行った結果，レーザスキャナの設置位置を車両座標系のもとで正確に同定できた。最後に，センサキャリブレーション値を使用して自律走行を行った場合，キャリブレーションしない場合よりも，走行精度が向上することを確認した。

［キーワード］2次元レーザスキャナ，ロボットトラクタ，ハフ変換，最小二乗法

*1 学生会員，北海道大学大学院農学研究科（〒060-8589 札幌市北区北9条西9丁目　TEL 011-706-2568）
*2 会員，北海道大学大学院農学研究科（〒060-8589 札幌市北区北9条西9丁目　TEL 011-706-3847）e-mail of corresponding author : noguchi@bpe.agr.hokudai.ac.jp