Engineering in Agriculture, Environment and Food 7 (2014) 7–13

Contents lists available at ScienceDirect

Engineering in Agriculture, Environment and Food

journal homepage: http://mama.agr.okayama-u.ac.jp/AABEA/

Research paper

# Development of a laser scanner-based navigation system for a combine harvester

Jongmin Choi, Xiang Yin, Liangliang Yang, Noboru Noguchi*

*Graduate School of Agriculture, Hokkaido University, Kita-ku, Sapporo, 060-8589, Japan*

A R T I C L E I N F O

*Article history:*
Received 15 July 2013
Received in revised form
9 December 2013
Accepted 11 December 2013
Available online 27 December 2013

*Keywords:*
Autonomous navigation
Crop row localization
Field profile modeling

A B S T R A C T

The objective of this study was to develop an autonomous navigation system using a laser scanner. A field profile was modeled by investigating range data. A crop row localization method was used to calculate the relative position and direction of crop rows. A steering controller was designed to guide the crop divider to move in an appropriate way. Results showed that the combine harvester had RMS errors of 0.02 m and 0.8° in terms of lateral offset and heading deflection, respectively, under stationary conditions. The corresponding root mean square (RMS) errors were 0.07 m and 3° when the combine harvester autonomously performed soybean harvesting at a speed of 0.97 m/s in the field.



## 1. Introduction

Traditional agriculture involves manual operations of tractors and implements, which are always tedious jobs for the operators. In rowed crop fields, the driver must work repeatedly for many hours to steer a combine harvester along crop rows. One solution for preventing fatigue and improving productivity and operation safety is to develop agricultural robot vehicles by integrating automatic or autonomous guidance systems that can automatically navigate agricultural vehicles to operate around the field instead of human beings. Researchers in the field of robot vehicles have made great progress over the past few decades, and various guidance systems have been developed as introduced by Reid et al. (2000) and Tillett (1991).

Some typical field robots based on a global positioning system (GPS) can perform autonomous operations such as tillage (Bell, 2000; Yukumoto et al., 2000), planting (Nagasaka et al., 2004), and cultivating and harvesting (Iida et al., 2006). Nagasaka et al. (2004) and Noguchi et al. (2002) used a real-time kinematic GPS (RTK-GPS) and fiber optic gyroscope (FOG) sensors to develop field robots that achieved good accuracy with an error of less than 10 cm. With the rapid development of image processing and computing, machine vision has become a popular and inexpensive approach for local navigation. Reid and Searcy (1991) used a Bayes classifier to detect crop rows by finding an optimal threshold for segmenting near-infrared images. Jiménez et al. (1999) reported that a laser range finder could be used to recognize spherical fruits and determine their three-dimensional positions, radius and reflectance. Kise et al. (2005) acquired navigation information on crop rows through processing stereo-images, reconstructing a three-dimensional field map and finding optimal navigation points. As depicted by Chateau et al. (2000), laser rangefinders were attached to different positions of the combine cab for multiple purposes under typical structured environments. Kise et al. (2005) developed an obstacle detection and identification algorithm for a laser range finder-based obstacle detector using a template matching function and a Kalman filter to detect the location of an obstacle, reconstruct its silhouette and estimate its relative motion. Oscar et al. (2007) developed an automatic guidance system that navigated a robot tractor between tree rows based on detection of tree rows by using a Hough transform to extract straight lines from range data measured by a laser scanner. Subramanian et al. (2006) separately used machine vision and a laser scanner to develop automatic guidance systems for navigating a common tractor through a citrus grove alleyway in both straight and curved shapes.

To obtain more detailed field information, a feasible method is to extend the field of view of vision sensors so that more comprehensive data can be acquired. In this study, a crop row guidance system for a CAN-bus-based combine harvester using a laser scanner that is mounted to a pan tilt unit on the cabin roof is described. Three-dimensional field information can be obtained when the pan tilt unit rotates the laser scanner in the vertical plane. The establishment of a system for soybean harvesting, a crop plant localization method using a cross correlation algorithm, and crop row detection in a rowed crop field are introduced in the following

* Corresponding author.
*E-mail address:* noguchi@bpe.agr.hokudai.ac.jp (N. Noguchi).

1881-8366/$ – see front matter 
http://dx.doi.org/10.1016/j.eaef.2013.12.002

section. Fundamental performance of the system was first evaluated under laboratory conditions. Then validation experiments were carried out by navigating the combine harvester to work along crop rows in a row-planted soybean field during harvesting season.

## 2. Research components

Fig. 1 shows a diagram of the laser scanner-based automatic navigation system. A combine harvester (AG1100, Yanmar) with engine power of 80.9 kW and divider width of 2.06 m was used as the platform. An integrated CAN-bus-based communication network connects all sub-systems including the steering system, header control system and sensors for detecting harvester status, making it easy to exchange information. In this study, the CAN-bus-based network also provided a standard interface for receiving commands from customized devices such as the navigation system. The key element of the automatic navigation system was a laser scanner (UTM-30LX), which was about 3 m above the ground when mounted on the combine cab through a pan tilt unit. The pan tilt unit was used to tilt the laser scanner up and down within a range of 21° at 2 Hz in the vertical plane to obtain three-dimensional field information between A and B in front of the combine harvester. Their specifications are shown in Tables 1 and 2, respectively. A vehicle personal computer (PC) was used for data acquisition from the laser scanner and pan tilt unit, implementation of programs related to crop row detection, and determination of appropriate steering angles in real time. During autonomous runs, the vehicle PC was capable of sending commands to the combine network through a CAN interface so that combine harvester could be steered according to outputs of the navigation system. An RTK-GPS (Trimble MS750) and IMU (JCS-7401) measured the vehicle position and direction information as ground truth when evaluating the navigation accuracy of the newly developed system in a row-planted soybean field.

**Table 1**
UTM-30LX specifications.

| Parameter | Description |
|---|---|
| Voltage | 12 V DC ± 10% |
| Measurement range | 0.1–30 m |
| Scanning angle | 270° [deg] |
| Distance error | 0.1–10 m: ±30 mm, 10–30 m: ±50 mm |
| Angle resolution | 0.25° [deg] |
| Response time | 25 ms |
| Direction | Count clockwise |

**Table 2**
Pan tilt unit specifications.

| Parameter | Description |
|---|---|
| Voltage | 12–30 V DC |
| Maximum load | 2.72 kg |
| Maximum tilt speed | 300°/sec |
| Angle resolution | 0.013° |

## 3. Methods

### 3.1. Field profile modeling

An understanding of the field shape is needed for navigating the combine harvester to run along crop rows. In this study, the field profile was modeled by investigating the spatial distribution of range data measured by the laser scanner in a row-planted soybean field.

As shown in Fig. 2, the laser scanner measures distances in the $X_LO_LY_L$ plane under its own Cartesian coordinate system ($O_L$, $X_L$, $Y_L$, $Z_L$) for each scan. The coordinate values are calculated using Equation (1).

$$\begin{bmatrix} X_L \\ Y_L \\ Z_L \end{bmatrix} = \begin{bmatrix} \rho \cdot \cos\theta \\ \rho \cdot \sin\theta \\ 0 \end{bmatrix}, \tag{1}$$

where $\rho$ is the distance between the laser scanner reference origin and the object, and $\theta$ is the angle of the beam direction away from the origin axis $O_LX_L$.

The vehicle Cartesian coordinate system has its plane $X_VO_VY_V$ on the ground plane and its origin fixed on the vehicle. By assuming that the axis $O_LX_L$ is parallel to the ground, the range data of crop plants relative to the combine harvester were obtained by rigidly transforming coordinates under the laser scanner system into the vehicle local coordinate system according to Equation (2).

$$\begin{bmatrix} X_V \\ Y_V \\ Z_V \end{bmatrix} = \begin{bmatrix} \rho \cdot \cos\theta \\ \rho \cdot \sin\theta \cdot \sin\beta \\ H - \rho \cdot \sin\theta \cdot \cos\beta \end{bmatrix}, \tag{2}$$

where $H$ is the height of the laser scanner origin $O_L$ above the ground ($H = 3$ m in this study), and $\beta$ (shown in Fig. 1) is the angle between the scanning plane $X_LO_LY_L$ and the vertical axis going

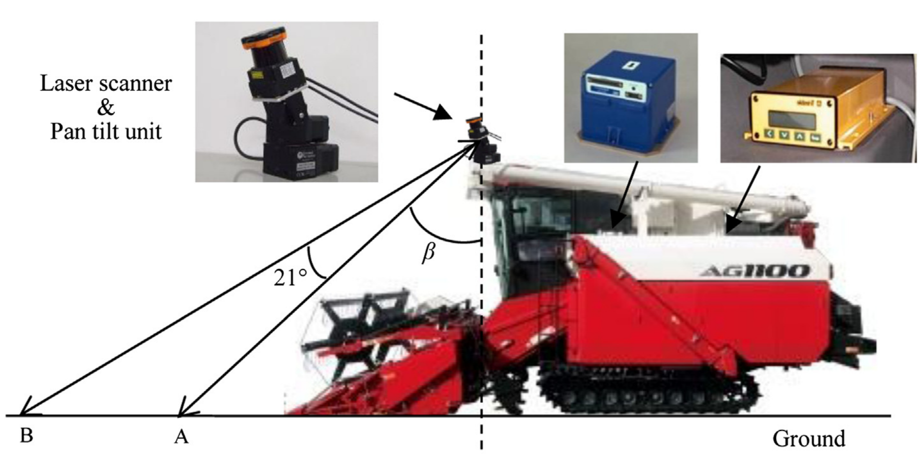


**Fig. 1.** Platform and components.