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Research paper

Autonomous positioning of the unloading auger of a combine harvester by a laser sensor and GNSS

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A B S T R A C T

The paper proposes a method for the autonomous positioning of the unloading auger of a combine harvester by a laser sensor and global navigation satellite system (GNSS). The proposed method positions the unloading auger to the target position by the following process. First, by using GNSS, GPS compass, and laser range finder (LRF) installed on the combine harvester, a three-dimensional (3D) map is generated and then converted into a top-view image. Then, the upper quadrangle of the grain container is detected from the top-view image by using upper quadrangle detection method and the target position of the unloading auger is calculated. Lastly, the target position is applied to the combine harvester to perform the positioning of the unloading auger. The results of the experiment show that the proposed method has sufficient accuracy to perform the positioning of the unloading auger onto the target positions.

1. Introduction

Automation of agricultural machinery has strongly attracted the attention of many researchers (Reid et al., 2000; Li et al., 2009; Mousazadeh, 2013). For cereal production, in particular, automation is a key technology that will lighten the workload of human operators. It will also enhance the agricultural productivity in developing countries, and at the same time, fill the workforce shortage in the developed countries that sometimes suffer from low birth rates and the consequent decrease in the population of agricultural workers.

Rice is a main staple in eastern Asia. Like for other cereals, a combine harvester is used for the harvest of rice crops. In Japan and Korea, a head-feeding combine harvester is widely used for rice harvesting. Thus, a project team of Kyoto University is studying the development of a head-feeding combine robot. Iida et al. (2013) has demonstrated autonomous rice harvesting with the combine robot. It created a target path and harvested rice crops by path following control with sufficient precision.

Typically, the harvested grain is stocked in the grain tank of the combine and needs to be regularly unloaded into the grain container, which is known as the unloading operation. Although researchers have tried to develop autonomous head-feeding combines, their studies focused only on the automation of harvesting (Iida et al., 2013; Saito et al., 2012). Thus, when the grain tank becomes full, the former prototypes are required to stop robotic harvesting, and its operator has to drive the combine to the nearby grain container and unload the grain. To automate the unloading operation, Kurita et al. (2012, 2014)) proposed a vision-based method for the automation of unloading operation. In their method, a machine vision does not directly recognize the grain container, but indirectly recognizes a planar board marker on the wagon. Moreover, they demonstrated the autonomous unloading operation under the field experiments.

Development of the autonomous combine has been gradually progressing as described above. When, in the future, a more sophisticated autonomous combine is developed and commercialized, farmers will be able to deploy the combine to various fields whenever they might desire. At present, rice harvesting is mostly performed in the daytime. However, in the future, there will be more demand to harvest crops at night,

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especially by large-scale farmers. Since the autonomous combines travel, based on the data from the GNSS, they can perform the harvesting operations regardless of the day or night time. On the other hand, a new unloading operation method in night time needs to be developed.

For autonomous unloading, the combine is required to recognize the grain container and obtain the relative positions and orientations between the two vehicles. Hence, the range information from the combine to the grain container is crucial. The use of a laser range finder (LRF) is a reasonable alternative to vision-based solutions. The LRF has been widely used for vehicle navigations in both indoor and outdoor environments (Surmann et al., 2003; Cole and Newman, 2006). As for their applications on the agricultural machinery, Barawid et al. (2007) detected tree rows for the tractor navigation in an orchard and Cho et al. (2014) detected crop rows of rice plants for the combine navigation. The LRF, however, has not been utilized for the tasks concerning the unloading operation, such as detecting a particular object or obtaining its relative position.

Thus, for the objectives of this paper, LRF, GNSS, and GPS compass were used to detect the grain container nearby the combine and carried out the autonomous unloading operations. Then, the performance was evaluated in the outdoor environment.

2. Materials and methods

2.1. Experimental setup

2.1.1. Research components

The sensors used in this study were an LRF (Hokuyo Automatic Co., Ltd., UTM-30LX), a GNSS (Topcon Co., Ltd., AGI-3), and a GPS compass (Hemisphere Co., Ltd., ssV-102). Each sensor is mounted on the roof (GNSS antenna and GPS compass) and the unloading auger (LRF) of the head-feeding combine harvester (Mitsubishi Agricultural Machinery Co., Ltd., VY446LM) as shown in Fig. 1. The functions of the sensors are as follows.

The LRF was used to perform two-dimensional scanning and to acquire the profile information of the terrain or the objects within the scanning range. Its specifications are shown in Table 1. We used the scan data within the ±60° range from the central axis of the LRF out of the total scanned data.

The GNSS was used to acquire the absolute position of the combine. A Multi-GNSS was used, which can respond to both the Russian GLONASS and the European GALILEO. A virtual reference station (VRS) system was employed to compensate for the signal errors generated by the sensors. The resulting positioning accuracy is ±0.03 m by using the VRS-RTK method.

The GPS compass was used to acquire the azimuth of the combine. While the GPS compass typically is used as the primary information source to acquire the azimuth, it may also use the backup information source obtained from the gyro and tilt sensor when the primary source cannot be accessed due to signal blocking. The azimuth accuracy of the GPS compass is within 0.5° RMS.

The specifications of the grain container (Taisho Co., Ltd., SBX-11N) are a length of 1.83 m, a width of 1.3 m, and a height of 1.17 m. As shown in Fig. 1, the grain container is mounted on the wagon deck, where the height of the grain container from a flat even ground was 1.77 m.

Table 1
LRF specifications.

Parameter	Description
Model	UTM-30LX
Accuracy	1.1 m–10 m: ±30 mm, 10 m–30 m: ±50 mm
Angular resolution	0.25°
Interface	USB 2.0
Scan angle	270°
Scan direction	Counterclockwise
Scan range	Guaranteed range: 0.1–30 m
Scan speed	25 ms

2.1.2. Embedded control system

For the integrated control of the components of the combine and the mounted sensors, two electronic control units (ECU)s, named ECU-KU1 and ECU-KU2, were developed in addition with the original ECUs (ECU-A and ECU-B), together with a remodeled pre-existing control system for the combine harvester (Iida et al., 2013). As shown in Fig. 2, the developed ECUs communicate via the control area network (CAN) bus, and are responsible for the following functions: ECU-KU1 communicates with the personal computer (PC) and via the RS-232C ports, transferring the data from the components and the data from the GNSS and GPS compass

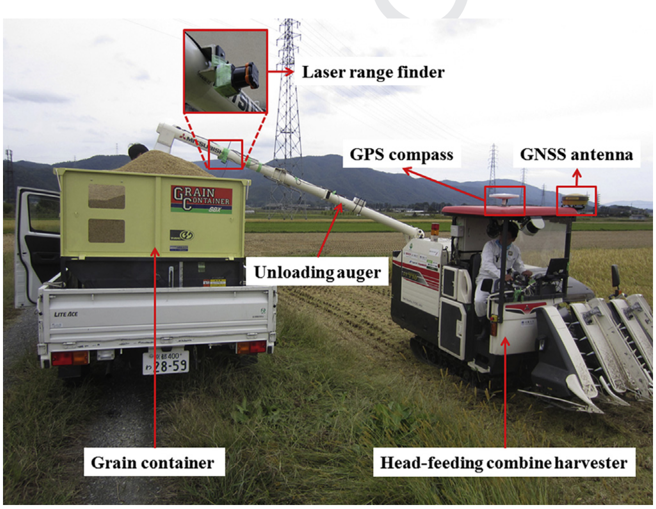

Fig. 1. Sensors mounted on the head-feeding combine harvester.

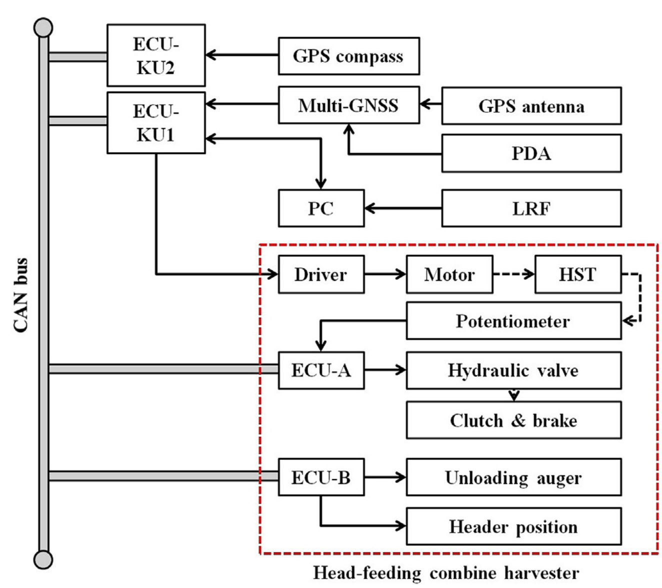

Fig. 2. Embedded control system architecture.

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