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Development and application of a wheel-type robot tractor

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ABSTRACT

In this study, a wheel-type robot tractor was developed in order to reduce agricultural labor. An RTK-GPS (real-time kinematic global positioning system) and an IMU (inertial measurement unit) were used as position and attitude sensors for the navigation system. A path-following navigation algorithm and an algorithm for turning at headland were designed in this study. Tuning of the auto-steering system to improve the navigation accuracy was done. Applications of the robot tractor including tillage, spraying and weeding were tested in real farms. The RMS (root mean square) of lateral error was less than 0.05 m for all of the applications. The results of the tests revealed that the robot tractor has high and stable navigation accuracy for the tested operations.

1. Introduction

A fully automatic wheel-type robot tractor was developed in this study in order to save agricultural labor. It was expected that the robot tractor would run on a predefined map automatically, and it was also expected that the vehicle speed, engine speed, up/down of hitch and on/off of PTO could be controlled automatically.

The most difficult and important research point for a robot tractor is how to steer the tractor automatically and correctly in a field. Researchers have tried using local sensors such as a camera or a laser scanner to develop an automatic tractor. A camera has been used since the 1990's (Billingsley and Schoenfisch, 1995; Hague and Tillett, 2001; Kise et al., 2005; Olsen, 1995; Reid and Searcy, 1988). A study has been done in our laboratory using a laser scanner to auto-steer a tractor along trees in an orchard (Barawid et al., 2007). However, there has no report showing that a tractor can be stably controlled by a local sensor for applications in a farm, because the local sensors always require reference objects such as crop rows or trees to follow on.

A global sensor, a global positioning system (GPS), has been used in our laboratory for developing a robot tractor (Kise et al., 2000). The robot tractor developed in our laboratory was the first generation robot tractor using a GPS. A crawler-type robot tractor was also developed in our laboratory using a GPS (Takai et al., 2014).

The objective of this study was to develop a second-generation wheel-type robot tractor using a GPS. A controller area network (CAN) bus was used in the second-generation robot tractor for data communication in order to improve the stability. A CAN bus has been used in recent years for tractors to improve automatic controllability (Hermann and Gerhard, 1999). Navigation accuracy was improved by finely tuning the steering system, and a steering angle calculation algorithm was designed to enable the robot tractor to following a predefined map. Steering angle was calculated by using dynamic look ahead distance according to the vehicle speed and the heading error. A turning algorithm was also designed to automatically turn the robot tractor at headland areas.

For application of the newly developed robot tractor to real farms, five tests were conducted in a field before and after planting crops in this study. The field conditions were no crops before planting and a wide space for the tractor to turn at the headland. After crops had been planted, a map was made to follow the crop rows and there was a narrow space for turning at the headland. For the planting operation, the field condition was similar to that for the operation before planting, and the seeding operation is therefore not discussed in this paper.

2. Tractor platform and sensors

2.1. Tractor platform

A wheel-type tractor (EG83, YANMAR Co., Ltd., Japan) was utilized as a tractor platform to develop the robot tractor. The specifications of the tractor are engine power of 61 kW, height, width

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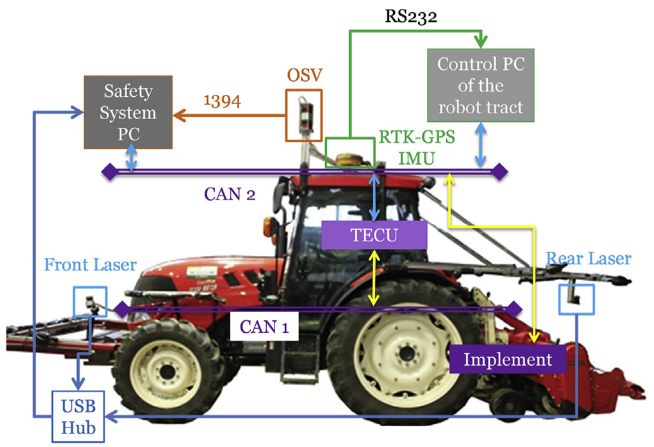

Fig. 1. Schematic diagram of the robot tractor system.

and length of 2.6, 1.8 and 3.9 m, respectively, and mass of 2840 kg. A schematic diagram of the robot tractor system is shown in Fig. 1. A control PC was installed to the robot tractor for the control algorithm, and another PC was installed for a safety system to obtain omni-directional stereo vision (OSV) information. A front and a rear laser scanners were used to detect obstacles near the tractor. Results of studies on the safety system were previously reported (Yang and Noguchi, 2012; Yang and Noguchi, 2014).

There are two CAN buses (CAN1 and CAN2) in the robot tractor system. CAN1 is used to transform the information inside of the tractor. The data format of CAN2 follows the ISOBUS (or ISO 11783) protocol. CAN2 is used to connect the control PC of the robot tractor, the PC for the safety system and implements. A tractor electronic control unit (TECU) was utilized to transfer data between CAN1 and CAN2, to control the hydraulic power auto-steering unit as well as the implement. The control units of the tractor included an engine controller, hydraulic mechanical transmission (HMT) controller, and hitch position controller. Data on status of the PTO and hitch are also fed back to the control PC by the TECU.

2.2. Navigation sensors

The navigation sensors used in this study were a real-time kinematic GPS (RTK-GPS) receiver (AGI3, Topcon Positioning Systems Inc.) and an inertial measurement unit (IMU). The IMU was integrated inside the GPS receiver. The horizontal position accuracy of the RTK-GPS is ± 0.03 m. In order to get fix solution for the RTK-GPS, a correctional signal that was received from a GPS Earth Observation Network (GEONET) service of Japan using a smart phone was transmitted to the RTK-GPS receiver by a RS232 at 1 Hz. The drift error of heading angle of the IMU was corrected by the RTK-GPS. Position and attitude data (roll, pitch and yaw) were sent to the control PC of the robot tractor by an RS232 at 10 Hz.

3. Navigation method

3.1. Navigation following a predefined map

A predefined navigation map is necessary for a robot tractor to operate in a field. The navigation map has two functions: to decide a running map for the robot tractor and to decide working functions of implements on the map. The working functions were defined by a series of codes that include engine speed, vehicle speed, PTO (on/off) and hitch (up/down).

The navigation map is defined in the world geodetic system 1984 (WGS84) coordinate systems. One path consists a series of points. One point has three parameters: the first and second parameters are latitude and longitude that define the coordinates of the point, and the third parameter defines the commands of the tractor and the implement. For example, a data set of a point in a field of Hokkaido University is [43.0744415, 141.336513, 115459], which indicates that the latitude and longitude of the point are 43.0744415 and 141.336513 deg, respectively, the command code of the point is 115459 (decimal value). The control value is decoded from the binary value of the code. The meaning of the command code is shown in Table 1.

As shown in Table 1, the 1st bit of the code indicates the job flag: 1 and 0 indicate start and stop, respectively. The implement is set at working mode and at idling mode when the job flag is start and stop, respectively. The path number is defined by the bits from the 2nd to 8th bits. The 9th bit defines engine speed mode: 1 is auto (engine speed being changed according to the working condition) and 0 is manual. The 10th and 11th bits define the shuttle direction: 01 is forward, 10 is backward and 11 is neutral. The vehicle speed is defined by the 12th to 15th bits. PTO command is on and off when the 16th bit is 1 and 0, respectively. Hitch positionpositon is up and down while the 17th bit is 0 and 1, respectively. The 18th to 64th bits are reserved for future application.

The start and end points of a path are decided by the ‘Job flag’, which is the 1st bit of the code. The start point of the path is the first point of which the ‘Job flag’ is changed from ‘0’ to ‘1’, and the end point of the path is the first point of which the ‘Job flag’ is changed from ‘1’ to ‘0’.

Fig. 2 shows a block diagram of the navigation method for the robot tractor. First, the navigation map was read by a software navigator, and position, velocity and attitude data were obtained from the RTK-GPS and IMU, respectively. Next, steering angle was calculated by the navigator by Eq. (1), and the control commands for the implement, such as PTO (on/off) and hitch (up/down) were decoded from the codes embedded in the navigation map as shown in Table 1. Finally, data for steering angle and control commands

Table 1
Meaning of the command code.

Decimal code: 115459 binary code: 1 1100 0011 0000 0011		Meaning
Bit	Binary value	
1	1	Job flag: 1 Start; 0 Stop
2–8	0000001	Path number: 0000001 Path 1
9	1	Engine Speed: 1 Auto (Changeable at running); 0 Manual
10–11	01	Direction: 01 Forward; 10 Backward; 11 Neutral
12–15	1000	Vehicle Speed: from 0000 to 1000 (Changeable at running)
16	1	PTO: 0 Off; 1 On
17	1	Hitch Position: 0 Up; 1 Down
18–64	0	Reserved

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