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Research paper

Optimization of steering control parameters based on a combine harvester's kinematic model

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ABSTRACT

The objective of this study was to optimize the control parameters of a robot combine harvester so that it can run along a straight line with minimal oscillation and minimal lateral error. A kinematic model was established by analyzing the relations among steering, control lever angle and performance of the vehicle. Based on the kinematic model, optimizations of a steering controller were conducted so as to obtain optimized control parameters. The optimized control parameters were verified by field experiments. In a stable state, the RMS value of lateral error was 0.025 m with a maximum of 0.066 m. Thus, the effectiveness of the method for optimization of control parameters of the robot combine harvester was verified.

Introduction

The Agriculture in Japan is facing many problems including aging and decrease of the agricultural labor force and low self-sufficiency rate. In order to solve these problems, the Ministry of Agriculture, Forestry and Fishery has been promoting the development of agricultural robots. For practical use of agricultural robots, a high level of accuracy in their operations is necessary to prevent damage to the field or crops.

To improve the accuracy of a robot's operations, various navigation sensors have been used for vehicle control. The most commonly used navigation sensors are a GPS (Global Positioning System) and an IMU (Inertial Measurement Unit). Noguchi et al. used the combination of an RTK-GPS, a fiber optic gyroscope (FOG) and an IMU to navigate a robot tractor (Noguchi et al., 2001). Kise et al. fused GPS and IMU and developed a robot tractor with a high level of operational accuracy (Kise et al., 2002), and Nagasaka et al. developed an automated transplanting machine by using these two sensors as well (Nagasaka et al., 2004). Other examples are a robot combine harvester (Iida and Yamada, 2006) and a crawler-type tractor (Takai et al., 2010). A critical step of the development of such robots is optimization or tuning of control parameters, particularly those for steering control.

The current method for tuning robot control parameters mainly depends on repeated trials during field experiments. With this method, the RMS value of lateral error of robot vehicles can be improved up to several centimeters. However, endless trials and experiments are extremely inefficient and tedious.

In this study, a novel method for optimizing control parameters of the steering angle of a robot vehicle was evaluated. In Section 2, the hardware used in this study and modeling of the vehicle are described. A steering controller and the parameters to be optimized are also described. Furthermore, an optimization algorithm is presented. In Section 3, optimization results and field tests of the optimized control parameters are presented. Conclusions are given in Section 4.

Materials and methods

Hardware

In this study, a combine harvester (Yanmar Co., Ltd – AG1100) was modified into a robot vehicle (Fig. 1). The combine harvester can be operated in both "manual mode" and "automatic mode".

In automatic mode, the combine harvester can be controlled by sending commands via a CAN bus. The safety of the combine harvester was also improved, since the vehicle will stop if commands are not sent to the machine every 200 ms. This control procedure ensures that the vehicle will stop immediately stop when the computer freezes.

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Fig. 1. The robot combine (Yanmar AG1100).

Modeling of the vehicle

A kinematic model must be constructed to optimize control parameters for steering the combine harvester. The combine harvester is controlled by a lever and a steering wheel. The lever controls the linear velocity of the vehicle and the steering wheel controls yaw angular velocity of the vehicle. Thus, it is necessary to determine the relations among linear velocity, yaw angular velocity, lever angle and steering angle.

In the first step, when the combine harvester is running in a straight line, the relation between lever angle and speed of the crawlers was measured, as shown in Fig. 2.

Thus, when the combine harvester travels in a straight line, its speed can be calculated by Eq. (1):

$$v_s = 0.0208l - 0.0134, \tag{1}$$

where v_s is velocity of the vehicle (m/s) in a straight movement and l is lever angle of the vehicle, which ranges from −100 to 100 with no unit.

Since one of the characteristics of the combine harvester is that the turning radius is solely determined by its steering angle regardless of the vehicle speed, the relation between steering angle and turning radius was determined. The relation is shown in Fig. 3.

The turning radius of the combine harvester can be calculated by Eq. (2):

$$R = 450.5(|\delta|)^{-1.318}, \tag{2}$$

where R is the turning radius (m) and δ is the steering angle of the vehicle, which also ranges from −100 to 100 and has no unit.

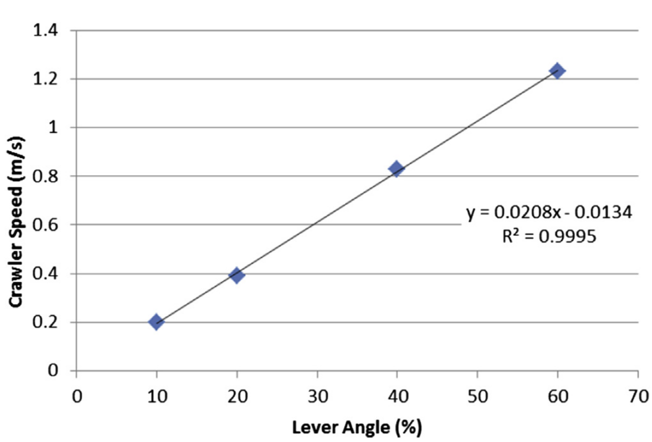

Fig. 2. Relation between speed and lever angle in straight movement.

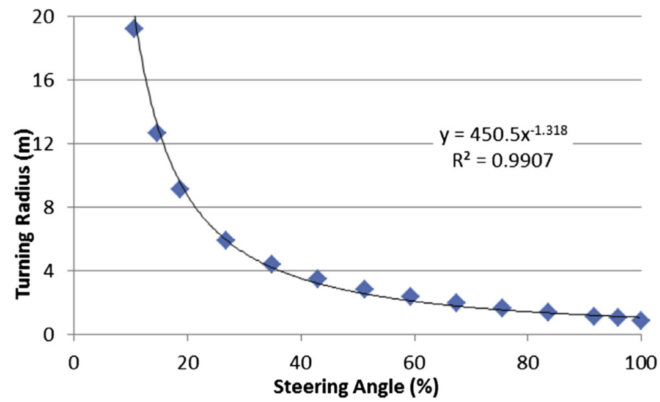

Fig. 3. Relation between turning radius and steering angle.

When the combine harvester turns, the outer crawler's speed remains the same, while the inner crawler's speed decreases. Given that the distance between the crawlers is 1.185 m, when the combine harvester turns, its speed (speed of the center of the crawlers) can be calculated by Eq. (3):

$$v_t = v_s\left(\frac{R}{R + 0.5925}\right), \tag{3}$$

where v_t is the vehicle's (center of the crawlers) speed (m/s) during turning, v_s is the vehicle's speed (m/s) in a straight movement (outer crawler's speed) and R is the turning radius (m) calculated by Eq. (2).

In the simulation program, the combine harvester's position and heading angle were calculated by the following method.

When the combine harvester is turning, it moves in an arc, and the method shown in Fig. 4 was used.

Assuming that combine harvester's current coordinates are (x_0, y_0) with a heading angle of φ_0 and yaw angular velocity of ω; after a short period of time Δt, the combine harvester's coordinates (x_t, y_t) and heading angle φ_t can be calculated by Eq. (4) and Eq. (5).

$$\begin{pmatrix} y_t \\ x_t \end{pmatrix} = \begin{pmatrix} y_0 \\ x_0 \end{pmatrix} + \frac{\delta R}{|\delta|}\begin{pmatrix} \cos\phi_0 & \sin\phi_0 \\ -\sin\phi_0 & \cos\phi_0 \end{pmatrix}\begin{pmatrix} \sin\Delta\phi \\ 1 - \cos\Delta\phi \end{pmatrix} \tag{4}$$

$$\Delta\phi = \phi_t - \phi_0 = \omega \times \Delta t, \tag{5}$$

where, according to Eq. (1), Eq. (2) and Eq. (3), yaw angular velocity ω can be calculated by Eq. (6):

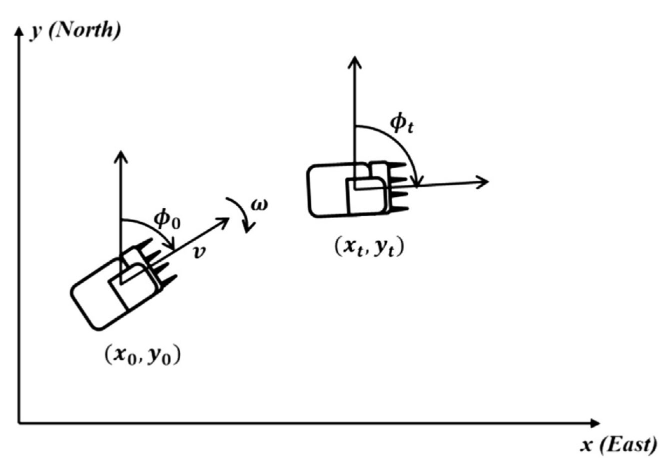

Fig. 4. Calculation of position and heading angle.