Research article

Guidance of a Transplanting Skid Steer Vehicle with Variable Center of Gravity

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Abstract In this study it is proposed a photovoltaic powered farming robot system that consists of a delivery vehicle and a working vehicle. The proposed system is designed based on a newly proposed farming method called shaft tillage cultivation. So, we have developed two automatic vehicles, as well as a 2-D localization method for positioning of the working vehicle. In addition, we have developed an attachment for shaft tillage and transplanting which is derived from commercially available transplanting machines. This movable transplanting attachment was mounted over two rails which are disposed transversally on the frame of the working vehicle which in turn permits transplanting multiple rows. The working vehicle is based on a skid steer vehicle with independent left and right motors that allow for motion direction control by turning the left- and right-side wheels at different velocities. However, within the field, even if same turning velocities are applied to both left- and right-side wheels a yaw angle is generated due to the sinkage and rolling resistance. Additionally, controllability of the working vehicle is greatly affected by variable changes of the center of gravity caused by lateral motion of the transplanting attachment. So, this paper focused on the effect of the position of center of gravity on the yaw angle in the working vehicle. The least square method was examined as method to find out the instantaneous center of rotation (ICR) and its effectiveness was confirmed. When the position of center of gravity was on the faster wheels the turning of the skid steer vehicle was more difficult than in other positions. The ICR changed even when the left- and right-side wheels were driven at the same velocities. Therefore, considering the position of center of gravity in the skid-steer vehicle would allow a rational guidance of the vehicle.

Keywords transplanting, skid steer vehicle, trajectory, variable center of gravity

INTRODUCTION

A current trend in agricultural area is the development of mobile robots and autonomous vehicle for precision agriculture. These are usually required to travel across unpaved terrains to operate or transport material. In this kind of terrains, the mobility and the controllability of the robot is strongly influenced by the physical properties of the terrain (Gonzalez et al., 2009).

Authors are involved in the development of a photovoltaic powered farming robot system that consists of a delivery vehicle and a working vehicle (Tajima et al., 2008). The proposed system is designed based on a newly proposed farming method called shaft tillage cultivation method which promotes weed and crop coexistence. Figure 1 shows an image of cross section of plants cultivated with the shaft tillage method. The tool has two different diameter sections as is shown in Fig. 1. The principal characteristics of this farming method are to minimize the power required when tillage and weed control is done separately by trimming periodically (Tajima et al., 1996). Shaft tillage cultivation method involves drilling a vertically shaped shaft with the rotary sinker that achieves an effect of tillage and the soil is not exposed on the surface of the field (Tajima et al., 1997). As such, we have developed two automatic vehicles. Figure 2 shows the developed photovoltaic powered farming robot system. Functions such as, transportation and positioning of the robot system, electric power generation and storage, transportation and supply of seedling trays etc. were distributed in these two vehicles. The delivery vehicle is guided outside the field through a magnetic tape and has functions such as, positioning of the working vehicle, electric power generation and storage as well as transport and seedlings supply. On the other hand, the working vehicle receives control information, power and a seedling supply from the delivery vehicle, and has function of positioning and transplanting of seedlings. Positioning of the working vehicle is being carried out by a 2-D localization system using a laser distance sensor (Tatsuno et al., 2005). In addition, we have developed an attachment for shaft tillage and transplanting which is derived from commercially available trans-planter. This movable transplanting attachment was mounted over two rails which are disposed transversally on the frame of the working vehicle which in turn permits transplanting multiple rows. The transplanting attachment is equipped with a tillage device for transplanting and a seedling tray tank which also move transversally within the frame of the working vehicle.

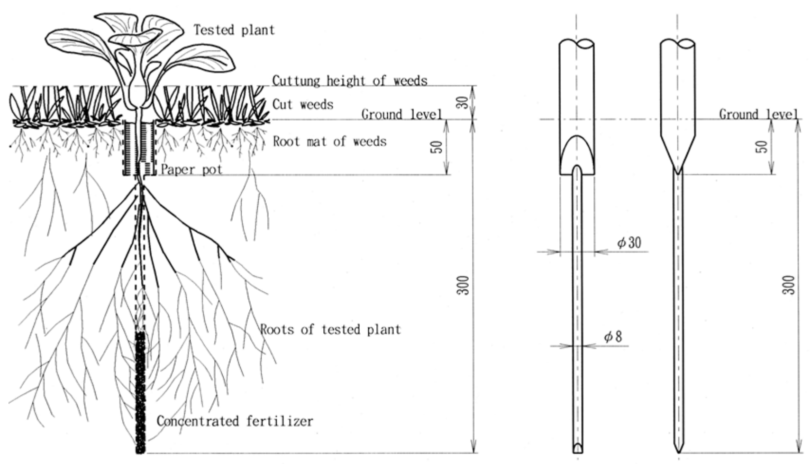
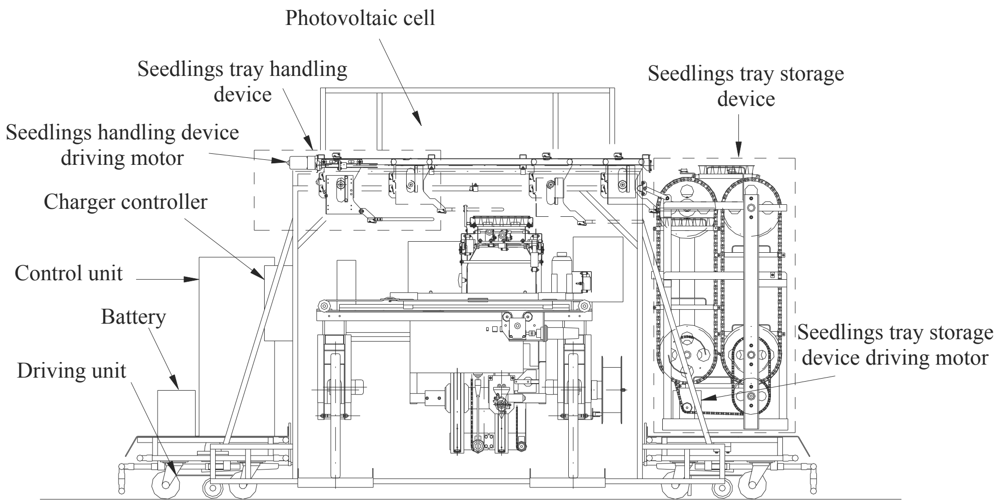
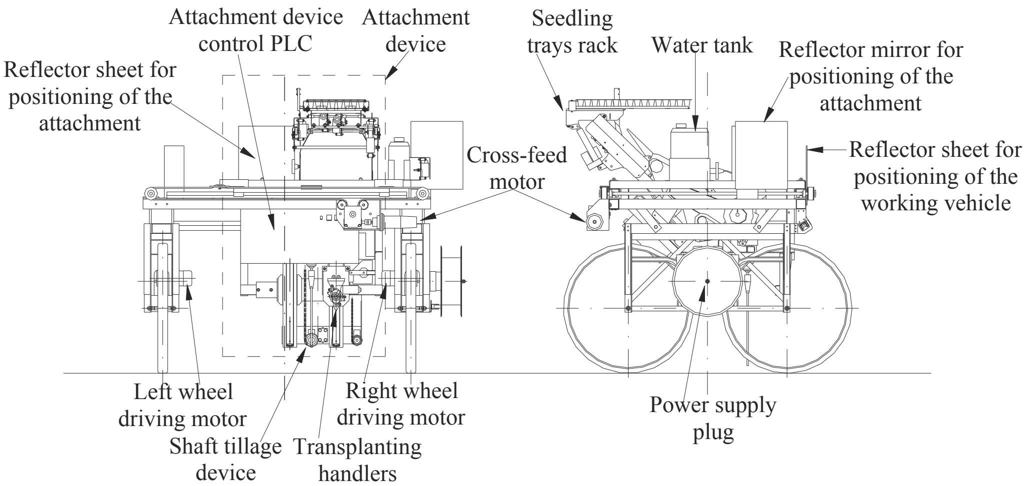


Fig. 1 Cross section of plant under cultivated by the shaft tillage method and the rotary sinker for the shaft tillage cultivation



(a) Delivery vehicle



(b) Working vehicle

Fig. 2 Photovoltaic powered robot system

The working vehicle is based on a skid steer vehicle with independent left and right motors (Tajima et. al. 2003). As the right- and the left-side wheels are driven independently, the wheel speed and direction of rotation determine the direction of the skid steer vehicle. Skid-steer vehicle is capable of zero-radius, "pirouette" turning. This is very important for positioning the skid steer vehicle when transplanting due to its facility in correcting the position in polar coordinates. In other words, the vehicle can turn based on a specific vertical axis within the frame. This system is designed to carry out multitasking. So eventually, it would be possible to perform variable cultural practices (by changing the attachment) using a manipulator, such as disease detection and control by image processing (Velazquez et al. 2011) creating the necessity to combine the general coordinates system in the field with that in the image so a more accurate positioning of the working vehicle could be achieved.

However, within the field, even if the same turning velocities are applied to both left- and right-side wheels a yaw angle is generated due to the sinkage and rolling resistance. Additionally, mobility and controllability of the working vehicle is greatly affected by changes in the position of center of gravity caused by lateral motion of the attachment. It is known that the turning characteristics of a skid steer vehicle are highly dependent on the position of center of gravity, especially for lateral changes (Sasaki et al. 2005), though enough knowledge has not been obtained for the development of an algorithm to guide the proposed system where the center of gravity moves transversally while traveling.

OBJECTIVE

The objectives of this paper are to find out the effect of the position of center of gravity on the yaw angle in the working vehicle and to consider a method to find out the instantaneous center of rotation.

METHODOLOGY

In order to measure a turning circular trajectory, it takes a lot of time due to the velocity of our skid steer vehicle is very slow, when the circular trajectory is large a wide area is needed and it is difficult to maintain the same ground conditions. Therefore, an accurately method to find out the ICR and the turning radius (R) from a small trajectory was necessary. In that respect, the least squared method was proposed.

Experiments were carried out inside a greenhouse using the skid steer vehicle showed in Fig.3. This skid steer vehicle is based on the Agri-cart manufactured by Alumis Co., Ltd. Turning experiments were carried out at very low speed. As power supply a regulated power DC supply was used. PWM driver was used for control of the left- and right-side motors. A load of 196 N was used for all experiments. Tires pressure was set to 196 kPa. 9 load conditions were set as is shown in Fig. 4. Driving speeds of the wheels were set as shown in Table 1. The turning direction was set to counterclockwise. Experiments were conducted as follows: First the load on each wheel was measured for each condition of the load. A mark was collocated each 90 degrees on the right-front and left-rear wheels. Then after traveling a distance of 2 m, 8 m trajectory was plotted on the ground. Plotted points were then measured in Cartesian coordinates with a tape.

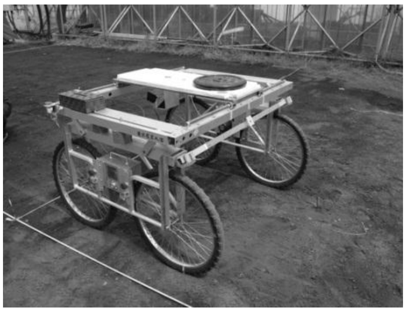


Fig. 3 Skid steer vehicle

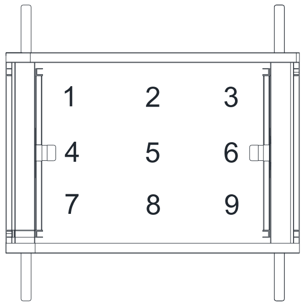


Fig. 4 Load conditions (Top view)

Table 1 Driving setting speed of the wheels

Speed setting	Left-side angular Speed ω_l (rad/s)	Right side Speed ω_r (rad/s)
1	0	1.24
2	0.64	1.24
3	1.20	1.24

Least square method

The turning radius and ICR were calculated using the least square method. Eq. (1) represents the equation for a circle. This method is based on minimizing the mean square distance from the circle to the data points

$$x^2 + y^2 + ax + by + c = 0 \tag{1}$$

Where $\left(-\frac{a}{2}, -\frac{b}{2}\right)$ represents the center of the circle and $\frac{\sqrt{a^2+b^2+c}}{2}$ represents the radius. The residual ε_i obtained from the circle trend line and data points, x_i and y_i, obtained from the trajectory of the skid steer vehicle are expressed by Eq. (2).

$$\varepsilon_i = x_i^2 + y_i^2 + Ax_i + By_i + C = 0 \quad (2)$$

Then the squares of the residuals ε_i^2 are summed and A, B and C are determined so that the sum is minimized as shown in Eq. (3). Here, A=-2a; B=-2b and C=a^2+c^2-r^2.

$$S = \sum_{i=1}^{n} \varepsilon_1^2 = \sum_{i=1}^{n} (x_i^2 + y_i^2 + Ax_i + By_i + C)^2 \quad (3)$$

Particularly, the estimated values of A, B and C can be obtained by partial differentiation and equating to zero.

RESULTS AND DISCUSSION

Figure 5 shows the load on wheels under the 9 load conditions (Fig. 4). The load was distributed symmetrically for load condition 5 on the left-and right-sides of the vehicle with values from 201-249N. The load moved to right-side for condition 6 and to left-side for condition 4 confirming that the center of gravity moved along with the load. Fitting the circle equation to plotted data points with the least square method allowed calculating the ICR and turning radius, from a small trajectory in a short time, confirming the effectiveness of the method.

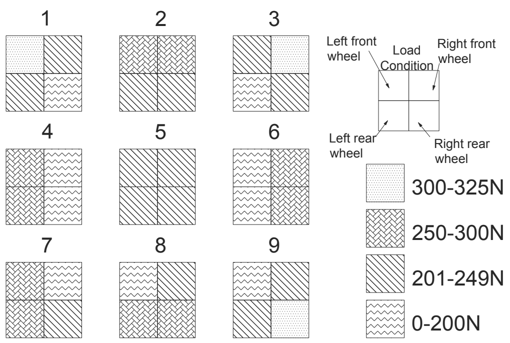


Fig. 5 Load on wheels

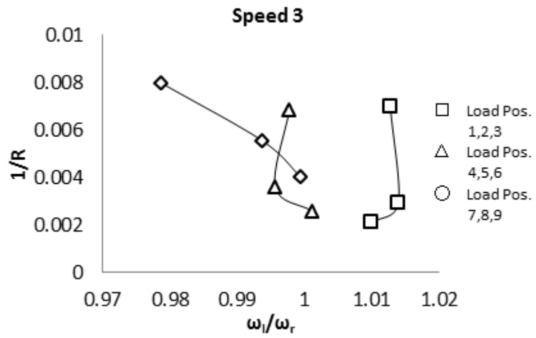


Fig. 6 Relationship between ω_l/ω_r and 1/R for Speed setting 3

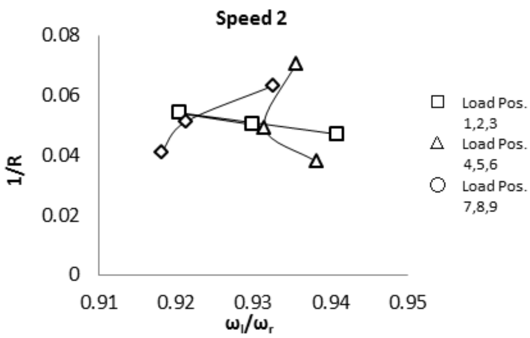


Fig. 7 Relationship between $\omega_l/\omega_r$and 1/R for Speed setting 2

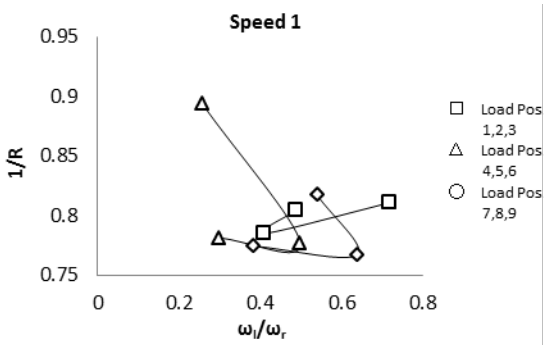


Fig. 8 Relationship between ω_l/ω_r and 1/R for Speed setting 1

Figures 6, 7 and 8 show the relationship between the ratios of ω_l/ω_r and 1/R. R represents the turning radius and ω_l and ω_r are the left- and right-side wheels angular speed, respectively. As it can be observed in each figure the turning radius varied for each load condition even when experiments were carried out under the same speed and ground setting conditions. When the load was on the faster wheel (right-side), braking effort on the slower wheel (left-side) reduced as a result of wheels sinkage and rolling resistance making the turn more difficult. On the other hand, when the load was over the slower wheel (left-side) the braking effort increased facilitating the turn. In other words, when the load is over the faster side the vehicle tends to travel straight and when the load is over the slower side the vehicle tends to tight turn.

CONCLUSION

The least square method fitting the circle equation was proposed and examined as a method to find out the turning radius and the ICR of the vehicle from plotted point data obtained from a short trajectory and its effectiveness was confirmed. The ICR changed even when the left- and right-side wheels were driven at the same speed. Considering the position of center of gravity in the skid-steer vehicle would allow for a rational guidance of the vehicle. Hence, analytical studies are necessary in order to achieve a more accurate control for positioning of the skid steer vehicle. In other words, mathematical modeling (equations of motion) and simulation of the working vehicle taking into account changes in the position of the center of gravity are required. As a result, velocities for the left- and right-side wheels as well as the appropriate position of the center of gravity could be obtained. Finally, in order to evaluate the accuracy of the mathematical model, comparison between experimentally obtained data and those obtained by simulation is required.

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