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Vision-Based Speed and Yaw Angle Measurement System

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Abstract. We propose a system that is able to detect vehicle speed and yaw angle based on vision sensors. In rice fields in Japan, rice is transplanted in an ordered grid pattern. We have already developed a vision system able to estimate plant positions with high precision based on this lattice layout. In this study, the inclination to the crop rows of vehicles (Yaw angle) was calculated from the crop position information acquired using our vision system. Next, two time lag images were compared and the speed of the vehicles was computed by tracing the motion of the same plant. Furthermore, the tracks of vehicles were calculated using these two sets of data. As a result of comparing the computed tracks with the position information obtained by a RTK-GPS, when it was assumed that the RTK-GPS's error was 0, the vehicle's position was detectable within 30mm error.

Keywords. Plant Position, Rice Fields, Vision sensor, Yawing angle, Vehicle speed

INTRODUCTION

In an attempt to reduce the driver's labor load in fieldwork and to reduce the rate of the machine cost occupied in production cost by increase the operating rate of the machine, many researchers have been working on the development of autonomous vehicles. The conventional method uses the high-precision position information offered by RTK-GPS, and direction information provided by FOG, and high-performance prototype systems have been reported. However, the RTK-GPS and FOG systems are very expensive, and considering the cost of introducing such systems, and the base tractor price, it is not realistic to apply these systems to small tractors of less than 100ps. Furthermore, the information supplied from GPS and FOG concerns only position and direction, and in order to develop a system able to deal with the growth of the plants or obstacles in the field, other sensors need to be added.

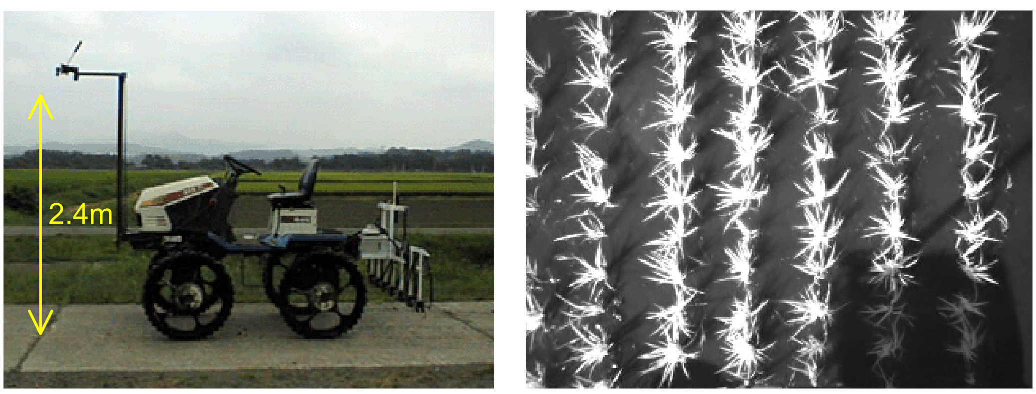
Vision sensors can provide the same information as normal human vision, and a large amount of information, such as growth rate, leaf color, disease, insect damage, lodging and obstacles are included in the field images obtained by this type of sensors. Although there is little practical use of vision sensors in agricultural production at present, with the low cost of vision sensors and the improvements in the operating capabilities of CPUs in resent years, research aimed at the application of vision sensors to agricultural productions is sure to progress.

Last year, we developed a measurement system for the accurate estimation of the rice plant position from field images captured by a vision sensor, based on the fact of rice being arranged in a lattice layout in Japanese rice fields. The system was robust to factors such as vehicle shadow and sunlight on the crop surface, and was stable in actual field conditions. If this system is carried on a vehicle and runs in a field, it is possible to calculate relation between the plants and the vehicle (i.e. Yaw angle) from the captured images. By comparing plant positions in two field images with a time lag, the running speed of the vehicle was also computable. Thus, an autonomous operating system using a cheap vision system may be built, without the need for expensive RTK-GPS and FOG systems. In this paper, we propose a method to detect a vehicle's yaw angle and speed, and examine the detection accuracy.

METHODS

Acquisition of Field Images

In Japanese rice fields, a special vehicle for management work, such as weeding, fertilizing, and spraying pesticides, is often used. For this study, a management vehicle (ISEKI, JK-11) was employed. A support beam was attached to the front of the vehicle, then a CCD camera (Sony Model No. XC-EI50, 1/2inchCCD) with an NIR pass filter was fixed facing downward at a height of 2.4m (Figure 1-a). The focal length of a lens was 6mm and 1.5(v) x 2.1(h) m of field image was captured at once (Figure 1-b). NTSC signals from the camera were captured every 100 msec by a personal computer via a frame grabber board (Cyber-tek Model No.CT-3000A) as 640x480 pixel images.



(a) (b)

Figure 1 a. Experimental setup for capturing field images

b. An example of a captured image

Detection of Plant Positions.

To detect plant positions, we used a newly developed algorithm. In Japanese rice production, rice plants are transplanted in order at intervals of about 15cm vertically and 30cm horizontally. The algorithm uses this special lattice layout to detect plant positions.

We created a template consisting of 9 hill models. Each hill was modeled as a Gaussian Densities. The noticeable feature is that information on both intra- and inter-hill spacing are included in this template (Figure 2).

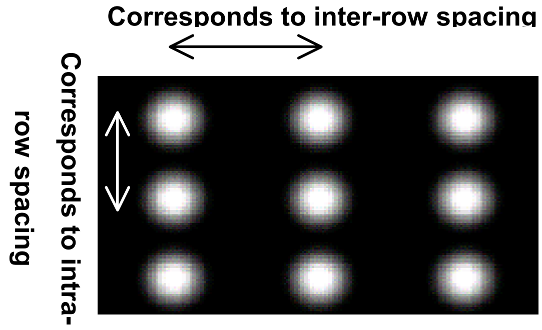
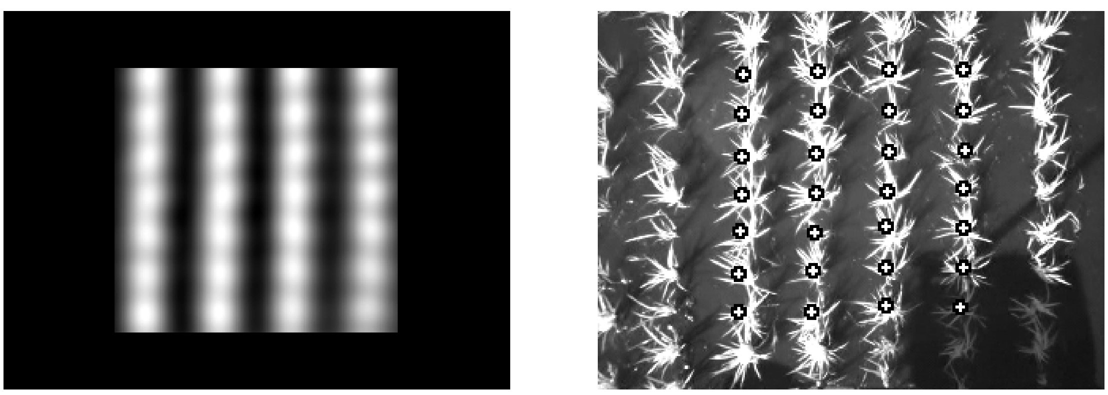


Figure 2. Template

Next, we calculated a cross-correlation-function image between the captured image and the template (Figure 3-a). The brightness of each point in the cross-correlation-function image shows the extent of correlation between the captured image and the template image. A number of very bright correlative points show the existence of plants. We took each peak as the center of the plants (Figure 3-b).



(a) **(b)**

Figure 3 a. Calculated cross-correlation-function image

b. Result of crop detection

Detection of Yaw angle

Since the camera is fixed rigidly to the vehicle, the yaw angle is calculable by measuring the slope of the crop rows.

1) In order to obtain the yaw, we must first translate the camera coordinate system from a pixel-based coordinate system (*x, y*) to a length-based coordinate system (*x', y'*). One pixel of the captured image corresponds to 7.6(H) x 8.2(V) mm. So the translation is accomplished by using Equations (1), where the origin of camera coordinate system is the center of the image, and the *y* or *y'* axis corresponds to the forward progress of the vehicle.

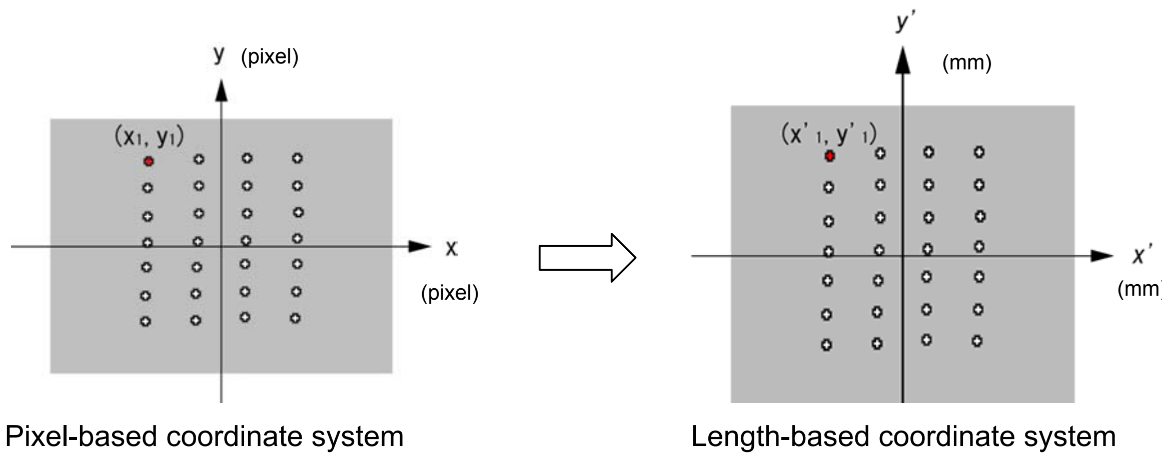
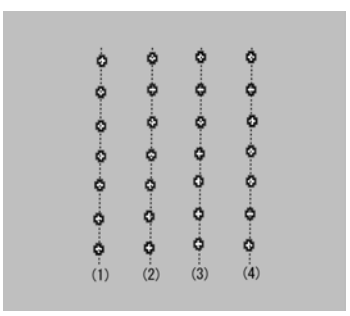


Figure 4. Translation of coordinate system

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 7.6 & 0 \\ 0 & 8.2 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \qquad (1)$$

2) The algorithm detects the plants for a number of crop rows at once. So multiple regression lines can be calculated based on the major axis method (Figure 5).



(1) $y = a_1 x + b_1$

(2) $y = a_2 x + b_2$

(3) $y = a_3 x + b_3$

(4) $y = a_4 x + b_4$

Figure 5. Calculated regression lines

The regression lines are expressed based on the direction of forward progress of the vehicle, and the yaw angles are expressed based on the crop rows. Thus, each yaw angle comes from Equation (2).

$$yaw_k = \begin{cases} \sin^{-1}\left(\dfrac{1}{\sqrt{1+a_k{}^2}}\right) & , \quad a_k > 0 \\ \sin^{-1}\left(\dfrac{-1}{\sqrt{1+a_k{}^2}}\right) & , \quad a_k < 0 \end{cases} \qquad (2)$$

The representative yaw angle *Yaw* is calculated as an average of the values of the yaw angles by Equation (3).

$$Yaw = \frac{yaw_1 + yaw_2 + \quad \cdots \quad + yaw_n}{n} \qquad (3)$$

where

n : number of calculated regression lines

Calculation of Vehicle Speed

In figure 6, the plant positions within the scope of the camera are expressed in two steps. First, the plant position (*x'crop, y'crop*) is expressed as Equation (4) based on the *y'*- Axis which corresponds to the direction of forward progress of the vehicle using the camera coordinate system (*x', y'*). Second, the plant position is expressed as (*Xcrop, Ycrop*) using a global coordinate system (*X, Y*) that is based on crop rows. The yaw angle *Yaw* was already given in Equation (3). *L* is the offset distance from the center of gravity (COG) to the fixed position of the camera. If the COG position is given as (*Xcog, Ycog*) using the global coordinate system, the crop position (*Xcrop, Ycrop*) is calculated by Equation (5).

$$\begin{bmatrix} x'_{crop} \\ y'_{crop} \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \sqrt{x'^{2}_{crop} + y'^{2}_{crop}} \end{bmatrix} \qquad (4)$$

where

$$\alpha = -\sin^{-1}\left(\frac{x'_{crop}}{\sqrt{x'^{2}_{crop} + y'^{2}_{crop}}} \right)$$

The origin is the center of the image and the *y*'-axis corresponds to the direction of forward progress of the vehicle.

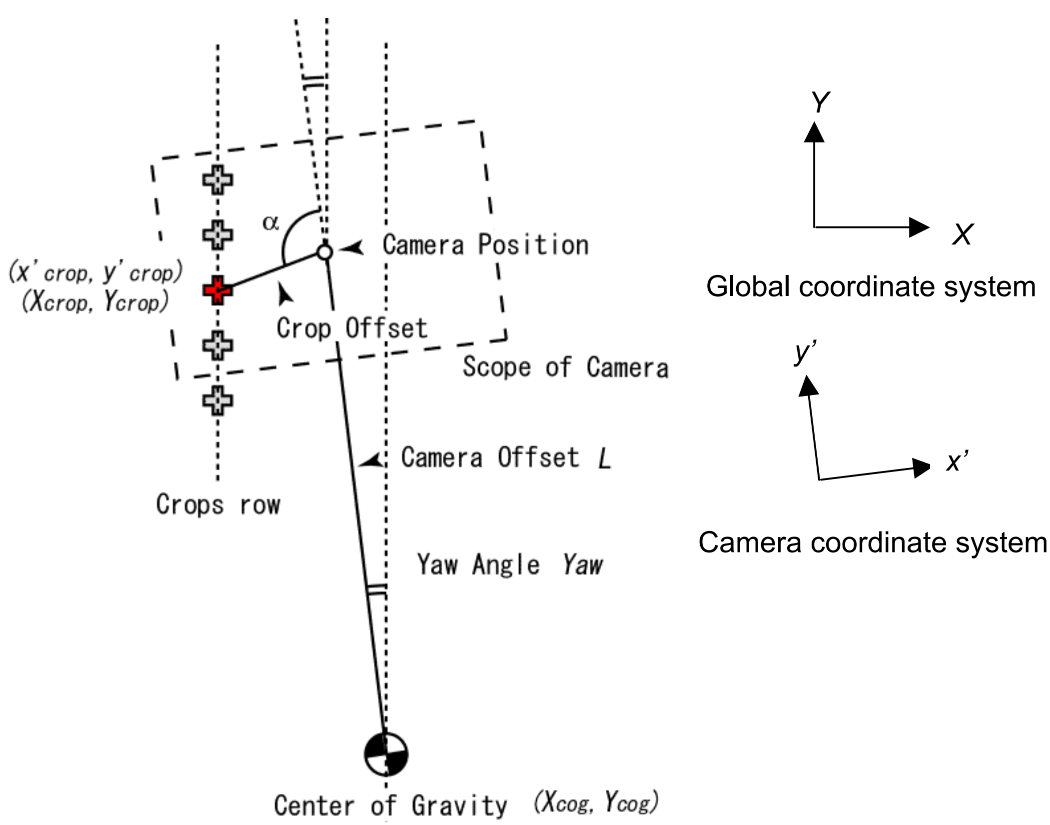


Figure 6. Camera and Global coordinate systems.

$$\begin{bmatrix} X_{crop} \\ Y_{crop} \end{bmatrix} = \begin{bmatrix} X_{cog} \\ Y_{cog} \end{bmatrix} + \begin{bmatrix} \cos Yaw & -\sin Yaw \\ \sin Yaw & \cos Yaw \end{bmatrix} \begin{bmatrix} 0 \\ L \end{bmatrix} + \begin{bmatrix} \cos(Yaw+\alpha) & -\sin(Yaw+\alpha) \\ \sin(Yaw+\alpha) & \cos(Yaw+\alpha) \end{bmatrix} \begin{bmatrix} 0 \\ \sqrt{x'_{crop}{}^2 + y'_{crop}{}^2} \end{bmatrix} \quad (5)$$

where

$$\alpha = -\sin^{-1}\left(\frac{x'_{crop}}{\sqrt{x'_{crop}{}^2 + y'_{crop}{}^2}} \right)$$

The origin is anywhere in the field and the *Y*-axis corresponds to the direction of the crop rows.

Figure 7 shows the time-lag movement of the vehicle. The COG position of the vehicle is expressed, first as (*Xcog0, Ycog0*), and next as (*Xcog1, Ycog1*), using the global coordinate system based on the crop rows. If we select one arbitrary plant in a captured image, its position is expressed in three ways. First, the plant position is expressed as (*x'crop0, y'crop0*) using the camera coordinate system (*x', y'*) based on the captured image 0. Second, the same plant position is expressed as (*x'crop1, y'crop1*) using the camera coordinate system (*x', y'*) based on the captured image 1. Third, the same plant position is also expressed as (*Xcrop, Ycrop*) using the global coordinate system (*X, Y*) based on the crop rows.

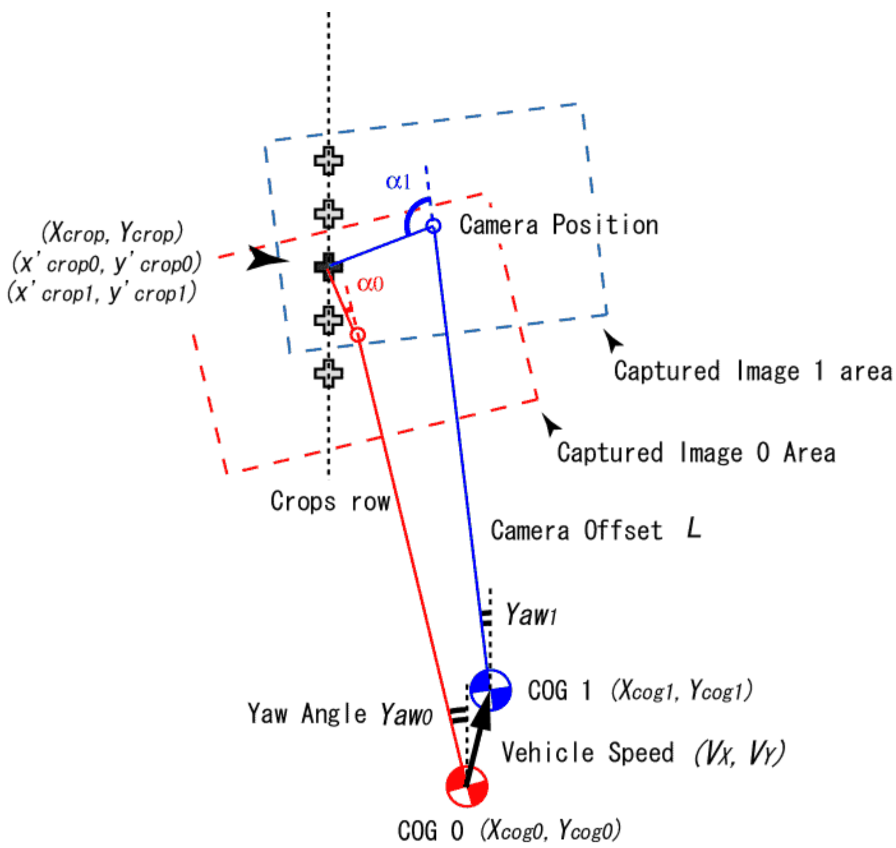


Figure 7. Motion of the vehicle.

The plant position (*Xcrop, Ycrop*) is expressed in two ways using Equations (6) and (7). Since the vehicle is moving, a different plant position is taken in each of the camera coordinate systems (*x', y'*). But, since the crop has not moved, the same value is taken in the global coordinate system (*X, Y*).

$$\begin{bmatrix} Xcrop \\ Ycrop \end{bmatrix} = \begin{bmatrix} Xcog_0 \\ Ycog_0 \end{bmatrix} + \begin{bmatrix} \cos Yaw_0 & -\sin Yaw_0 \\ \sin Yaw_0 & \cos Yaw_0 \end{bmatrix} \begin{bmatrix} 0 \\ L \end{bmatrix} + \begin{bmatrix} \cos(Yaw_0 + \alpha_0) & -\sin(Yaw_0 + \alpha_0) \\ \sin(Yaw_0 + \alpha_0) & \cos(Yaw_0 + \alpha_0) \end{bmatrix} \begin{bmatrix} 0 \\ \sqrt{x'^2_{crop0} + y'^2_{crop0}} \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} Xcrop \\ Ycrop \end{bmatrix} = \begin{bmatrix} Xcog_1 \\ Ycog_1 \end{bmatrix} + \begin{bmatrix} \cos Yaw1 & -\sin Yaw1 \\ \sin Yaw1 & \cos Yaw1 \end{bmatrix} \begin{bmatrix} 0 \\ L \end{bmatrix} + \begin{bmatrix} \cos(Yaw1 + \alpha 1) & -\sin(Yaw_1 + \alpha_1) \\ \sin(Yaw1 + \alpha 1) & \cos(Yaw_1 + \alpha_1) \end{bmatrix} \begin{bmatrix} 0 \\ \sqrt{x'^2_{crop1} + y'^2_{crop1}} \end{bmatrix} \quad (7)$$

where

$$\alpha_0 = -\sin^{-1}\left(\frac{x'_{crop0}}{\sqrt{x'^2_{crop0} + y'^2_{crop0}}} \right) \quad \alpha_1 = -\sin^{-1}\left(\frac{x'_{crop1}}{\sqrt{x'^2_{crop1} + y'^2_{crop1}}} \right)$$

Then, vehicle speed is calculated by Equation (8)

$$\begin{bmatrix} V_X \\ V_Y \end{bmatrix} * \Delta T = \begin{bmatrix} Xcog_0 \\ Ycog_0 \end{bmatrix} - \begin{bmatrix} Xcog_1 \\ Ycog_1 \end{bmatrix}$$
$$= \begin{bmatrix} \cos Yaw_0 & -\sin Yaw_0 \\ \sin Yaw_0 & \cos Yaw_0 \end{bmatrix} \begin{bmatrix} 0 \\ L \end{bmatrix} + \begin{bmatrix} \cos(Yaw_0 + \alpha_0) & -\sin(Yaw_0 + \alpha_0) \\ \sin(Yaw_0 + \alpha_0) & \cos(Yaw_0 + \alpha_0) \end{bmatrix} \begin{bmatrix} 0 \\ \sqrt{x'^2_{crop0} + y'^2_{crop0}} \end{bmatrix}$$
$$- \begin{bmatrix} \cos Yaw_1 & -\sin Yaw_1 \\ \sin Yaw_1 & \cos Yaw_1 \end{bmatrix} \begin{bmatrix} 0 \\ L \end{bmatrix} - \begin{bmatrix} \cos(Yaw_1 + \alpha_1) & -\sin(Yaw_1 + \alpha_1) \\ \sin(Yaw_1 + \alpha_1) & \cos(Yaw_1 + \alpha_1) \end{bmatrix} \begin{bmatrix} 0 \\ \sqrt{x'^2_{crop1} + y'^2_{crop1}} \end{bmatrix} \quad (8)$$

where

$$\alpha_0 = -\sin^{-1}\left(\frac{x'_{crop0}}{\sqrt{x'^2_{crop0} + y'^2_{crop0}}} \right) \quad \alpha_1 = -\sin^{-1}\left(\frac{x'_{crop1}}{\sqrt{x'^2_{crop1} + y'^2_{crop1}}} \right)$$

ΔT is the time lag between the captured image 0 and image 1.

Evaluation of the proposed algorithm

To evaluate the accuracy of the proposed algorithm, the tracks, the yaw angle, and the speed of a vehicle were calculated.

1) Field images (10frame/sec) and a RTK-GPS's positioning data (20data/sec) were acquired, while a vehicle equipped with both an image capture system and the GPS was operating in a field. The antenna of the GPS was fixed just above the COG point at a height of 2.4m. The vehicle speed was fixed at 250mm/sec during the operation. The crop rows in the field were a straight. And the vehicle was driven in a zigzag direction within limits, which prevented from running over the plants.

2) In the operation, images were taken for 15 seconds (150 frames), and the proposed algorithm was used to compute the yaw angle and the vehicle speed (Figure 8, 9).

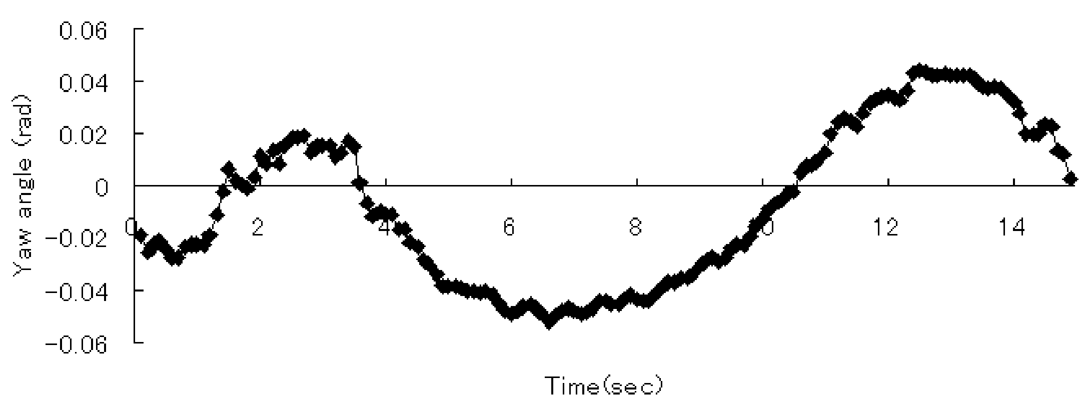


Figure 8. Calculated the yaw angle

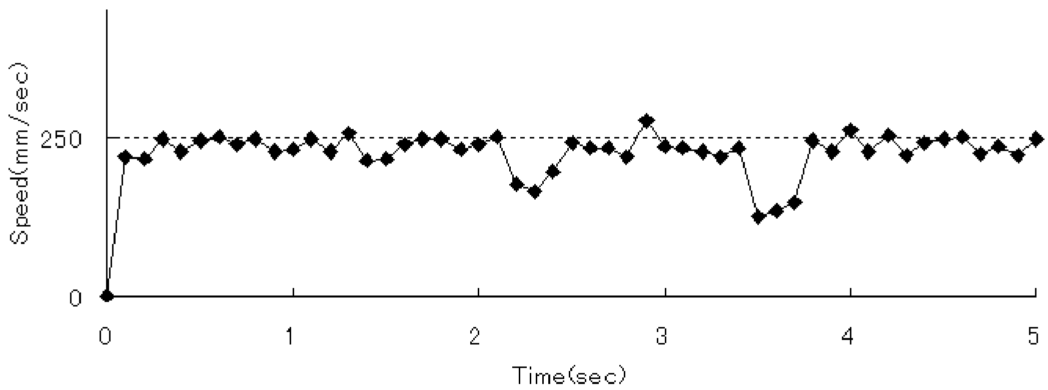


Figure 9. Calculated the vehicle speed

Next, the tracks of the vehicles were calculated using the proposed method, and plotted on a graph together with the positioning data obtained by the GPS (Figure 10). In the first section, the tracks calculated by the proposed method were unstable. The reason was considered as follows; (1) The camera, which attached at the end of the support beam, vibrate right and left caused by the vehicle's motion. (2) Therefore, the yaw angle of the camera and the yaw angle of the vehicle were different. (3) The vehicle's tracks were calculated based on the yaw angle of the camera in the proposed method, so the measurement error was occurred. But, the error does not accumulate while the yaw angle of the camera was detected accurately, the vehicle's track obtained by both the GPS and the proposed method were almost the same after the middle section.

3) Although the position information obtained by RTK-GPS is not necessarily in complete agreement with the tracks of vehicle and there is an error of about 20mm, when it was assumed that the position information was correct, the calculated R.M.S. error of the vehicle's tracks using this method was within 30mm in this short time test. However, in the long time operating, deterioration of the measurement accuracy caused by accumulated positional error is prospected.

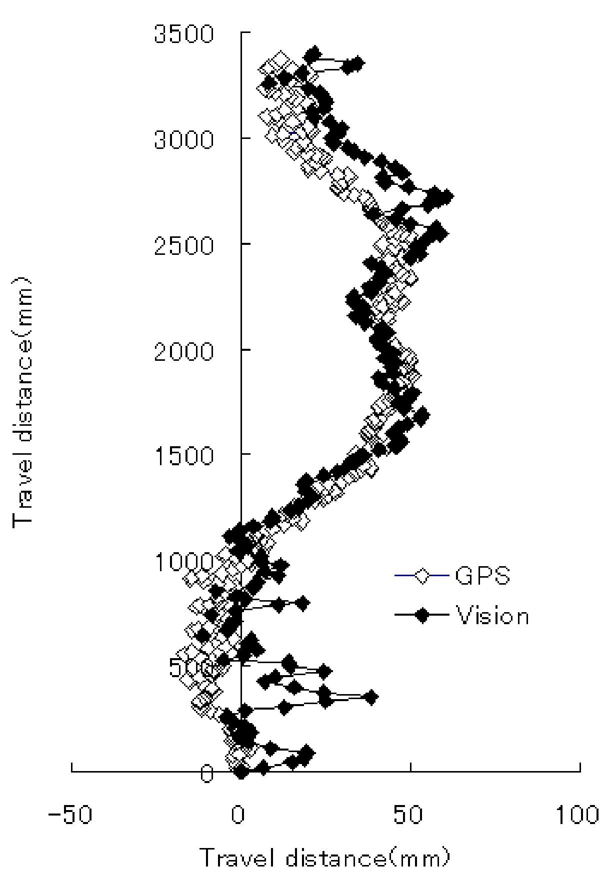


Figure 10. Calculated the vehicle tracks

CONCLUSIONS

We proposed a vision system that is able to detect vehicle speed and yaw angle. For our results, we could draw the following conclusions.

1) Yaw angle could be calculated using plant positions estimated using our algorithm.
2) Vehicle speed could be calculated using plant positions as shown in two images.
3) Using the yaw angle and the vehicle position, the tracks of the vehicle could be calculated within 30mm R.M.S error.

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