Navigation of autonomous vehicle for rubber tree orchard

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Abstract. This research has studied the navigation of autonomous vehicles in rubber tree orchards. It was emphasised on the rubber tree plantation in Thailand. Due to the high labour costs in the rubber industry and the demand for natural rubber has continued to decline over the past several years. The farmer were struggled to reduce the labour costs in production. The development of autonomous vehicle technology in rubber plantation can be a way to ease the production costs, such as reducing the amount of labour in fresh latex harvesting. This work was aimed to develop algorithm of a vision system for replacement of expensive sensors used in typical autonomous vehicles. The vision system model was implemented using only one camera installed on the vehicle to search for calibrated targets which were put on the rubber tree trunk. There were two important parameters, tree row offset and target distance, which were concerned when determining the performance of the autonomous vehicle in the rubber tree orchards. In order to evaluate the accuracy of the system, a set of experiments was conducted at a distance of 1-5 meters between the target and the camera. The results were compared between the controlled environment in the laboratory and the uncontrollable environment in the real rubber plantation.

1. Introduction

Automatic vehicles in rough terrain are one of the major trends in control research. Such vehicles can be used widely in agriculture applications which lead to the solutions of modern agriculture development. Less labor and resource are required for the automation system in agriculture. This technology can also replace human limitations and reduce operating cost. This research interests on the application of the ground vehicle automatically for agriculture in the rubber plantation. The rubber industry in Thailand has been struggled due to low profit and high labour cost [1]. In the process of the production, harvesting latex sap is a tedious work and uses a lot of labour. To minimize the operating cost, automation in the rubber tree orchard is one of the most promising technologies to resolve the problem.

The autonomous vehicle and orchard navigation system have been studying for many applications. Z. Wang et al. developed Machine vision assessment of mango orchard in the current orchard and season, the correlation coefficient of determination between machine vision estimates of panicle area and multi-view panicle count and fruit yield per tree [2]. C. Pirat et al. had developed vision Based navigation for the scalability analysis of the ESA Autonomous Transfer Vehicle Guidance, Navigation & Control (GNC) performances and the Russian docking system. This paper used a single monocular camera on the chaser satellite and various sets of Light-Emitting Diodes (LEDs) on the target vehicle ensure the observability of the system throughout the approach trajectory [3]. G. Bayar et al. had developed a model-based control method for an autonomous agricultural vehicle that operates in tree
fruit orchards. In the paper, they proposed an either state estimation or path following, relying instead only on data from a planar laser probability of a successful turn from one row into another, while respecting the maximum steering rate limits [4]. X. Zhang et al. did show an algorithm to the crop row detection for precision agriculture and automatic navigation. This research used a crop row detection method which was proposed for maize fields based on images acquired from a vision system. During the procedure of crop row detection, the position clustering algorithm and shortest path method were applied successively to confirm the final clustered feature point set [5]. W. Kunghun et al. had developed the vision model to use a single camera capturing calibrated targets based on the common pinhole model which were placed on the rubber tree trunks for study the errors and their uncertainties were monitored [6].

The prior works cited above did not focus on the operation between the trees rows. Most of the current researches of autonomous vehicle navigation systems had been using a laser scanner which is expensive and not practical for farming applications. In the rubber tree orchard, it is possible to permanently mount calibrated targets on the tree trunks and use them as the guidance for the autonomous vehicle system. The targets on the tree trunks for guidance the autonomous vehicle system will be easily searched by image processing technique. This method reduces the complication of terrain image processing and allows the mapping can be done with less performance computer platform. The same vision mapping technique can also applies to automatic navigation in other similar applications or other types of tree orchards.

This paper is aimed at finding ways to develop and implement vision system into the agriculture of natural rubber tree farming. The goal of this research is to develop an algorithm to autonomously guide a robotic vehicle platform along a rubber tree orchard row. There are two parameters important for navigation in the rubber tree orchard, target-camera distance parallel to the tree row and an offset distance between camera and tree row. This paper presents the test on real conditions in rubber plantations, which variations in the uncontrollable nature or the amount of light source that affects the parameters for navigation in the rubber tree row.

2. Orchard configuration and vision navigation to orchard geometry

2.1. Configuration of rubber tree orchard

The rubber tree orchard plantations usually have 3 meters row distance and 6-7 meters column distance. For the typical area of the plantation, it will use about 1600 square meters for 80 trees [1]. Rubber plantation farmers do harvest and rubber tree planting, etc. They work by walking along columns. Each column requires regular maintenance to facilitate daily work. The autonomous vehicle should therefore replicate the running path same as the work of the farmer.

The rubber tree orchard used in this research is well maintained and one of the rows was randomly selected as a test row. This experiment was conducted on a real rubber plantation located in Chachoengsao province, eastern of Thailand. The vision navigation was designed for 1-5 meter distance between row to row in the tree orchard. The sizes of rubber tree trunks were about 120-millimeter in diameter. In the actual orchard, it was found that there were several uncontrollable parameters which can affect the navigation performance. These include the straightness of rubber tree trunk, rough plantation areas of rubber trees and the amount of inconsistent light in each period. The effect of these parameters was compared with the system performance when working in controllable environment in laboratory.

2.2. Horizontal and vertical vision navigation to orchard geometry

The rubber tree orchard used in this research is well maintained and one of the rows was randomly selected as a test row. The vision model used for finding the rubber trees was developed based on the common pinhole model [7] as shown in Fig.1.
By capturing a known size target the image position and pixel length between P1 and P2, which were measured by the number of pixels, can be used to determine the position of the separated red target on the image plane as shown in Fig.2.

The target positions obtained from the pinhole vision model can only tell the positions of the trees in relation to the camera. To plan the camera path, these positioning data must be converted to the vertical vision navigation to orchard geometry model. Fig.1 shows the vertical plane of a rubber tree which is the target for the camera installed on an autonomous vehicle. The vertical vision navigation is very important because finding the separated red targets on the rubber tree to define as a region of interest (ROI) on an image plane. The image plane shown in Fig.2 is the picture retrieved from a webcam. Two red dots are detected as the targets. Then the center of both targets is identified as a position of rubber tree on image plane. Pixel position column on image plane, \((.1)\) \(p_x\) and \((.2)\) \(p_x\) are the pixel coordinates in a column of image plane, when \((.1)\) \(p_y\) and \((.2)\) \(p_y\) are the pixel coordinate in the row of image plane. A pixel length distance \(i\) is calculated between pixel positions of \((.1)\) \(p_y\), \((.2)\) \(p_y\), and \(P(x, y)\) is the center of image plane. This position data obtained from the pinhole model can be converted to the camera positioning on the orchard by the relationship of the vertical vision navigation on object plane.

The vertical model as shown in Fig.3 in the world coordinate is another significant angle for tracking separated Red target at install to rubber tree trunk. By estimate the optimum angles \(\lambda\) and distance \(H\), it can be derived as shown in equation 1 and 2 where the parameter of \(M = 0.1\) meters is the size of a single target. The view angle vertical field of view (VFOV) of the camera is \(\psi = 43.30^\circ\).
The distance between the centers of red target to center of separated target is $T = 0.35$ meters. The distance between centers of separated target to high edge of red target is $I = 0.4$ meters, and $f$ is the focal length of the camera.

$$\lambda = 2\tan^{-1}\left(\frac{T + \frac{M}{2}}{f \cdot \frac{2 \cdot T}{(l_i)}}\right)$$

(1)

$$H = \frac{f \cdot \frac{2 \cdot T}{(l_i)}}{\cos\left(\frac{\psi}{2}\right)} - (f \cdot \frac{2 \cdot T}{(l_i)})^2$$

(2)

**Figure.3** The vertical vision navigation object plane to orchard geometry model.

**Figure.4** The horizontal vision navigation object plane to orchard geometry model.
From this position P1 and P2 on image plane as shown in Fig.2, the target positioning data on the image plane obtained from the pinhole model can be converted to the camera positioning on the real orchard by the relationship of two parameters. It can be seen that it can estimate target-camera distance parallel to the tree row (S), offset distance between camera and tree row (O).

\[
S = \frac{2 \cdot f \cdot \sin(\theta) \cdot \cos(\theta) \cdot \left[ f \cdot \cos(\theta) + \xi \cdot \sin(\theta) \right]}{f \cdot l_i} \tag{3}
\]

\[
O = \frac{2 \cdot f \cdot \sqrt{\xi^2 + \left( f \cdot \cos(\theta) + \xi \cdot \cos(\theta) - 2 \cdot f \cdot \xi \cdot \sin(\theta) \right)}}{2 \cdot f \cdot l_i} \tag{4}
\]

When:

\[
\xi = \left( \frac{X_{(p,1)}}{2} + \frac{X_{(p,2)}}{2} \right) - \frac{W_i}{2} \tag{5}
\]

3. Experimentation Setup

From In this research, the experiment was made to compare between the controlled environment and the uncontrolled environment. By using actual rubber tree posts with 120 millimeters diameter, the camera used in this experiment has vertical field of view angle (VFOV) at 43.30º and a horizontal field of view angle (HFOV) at 70.42º for determining the region of Interest (ROI) on the image. The webcam Logitech C920 captured the images of the rubber tree with the size of 720x1280 pixels RGB image resolution on the world coordinate system as shown in figure 3. This dimension was based on the rubber tree trunk at the diameter of 120 millimetres. Each rubber tree was mounted with two red color bands with a vertical distance defined by the target length 0.7 meters. The target identifying method was made by capturing all frame rate the image frame in RGB format. Then, the image input was pre-processed by the kernel filter procedure this method is to eliminate the high frequency noise that is in the image or reduce the variance in the image to make the image more detailed. Because the Red target color was selected to be distinctive from the common rubber tree orchard background. After that, the target areas in image were classified by a low level gain and high level gain on HSV format. The Red value from the image was then sorted out and the image was set to binary image that the target was presented in white on black background. The target distance is 0.7 meters, to assess the accuracy and efficiency of parameter for navigation.

Figure.5 Detection of separate targets on the rubber tree on the uncontrolled environment of actual tree orchard
4. Results

Fig.6 has shown the magnitude errors of $O$ obtained from the navigation experiments by comparison between the controlled environment and uncontrolled environment. It can be seen that magnitude errors target row offset ($O$) in the controlled environment were minimal when comparing to uncontrolled environment and they were small throughout the test ranges. Because the area of the rubber plantation is different from the lighting conditions from the controlled environment, the rubber tree is not straightened the surface of the rubber plantation not flat terrain.

![Figure 6](image_url)

**Figure 6** The magnitude error of the target row offset ($O$) for uncontrolled and controlled environment.

The magnitude errors of the distance parallel to the target ($S$) Fig.7 when the camera locates in the longest distance from the target of the test is highly error compared the camera near to the target. In a controlled environment have the result of a constant magnitude error throughout the distance for testing. But the experiment for the uncontrolled environment throughout the test distance by the average is considered to have an error that is still acceptable.

![Figure 7](image_url)

**Figure 7** The magnitude error of the distance parallel to the target ($S$) for uncontrolled and controlled environment.
5. Conclusions

In this research, the navigation of autonomous vehicle for rubber tree orchard was successfully evaluated for the magnitude of errors. It has shown that the methodology was effectively applied to estimate the distance parallel to the tree row (S) and offset distance between camera and tree row (O) using two separated targets as the reference for estimating parameters in the actual rubber tree orchard. The experiment showed that different environments result in twice the accuracy of S and O parameters. By the maximum errors of O and S can be converted to the location errors in the tree orchard geometry, and it has shown the accuracy of 8.1 centimetres in the O-direction, 14.6 centimetres in the S-direction for uncontrolled environments and 5.1, 4.1 centimetres in the O-direction and S-direction for controlled environments. Though O-direction and S-direction of error seem to be large, the navigation of autonomous vehicle for rubber tree orchard method is still feasible. The next step will be to design an automatic car using a camera system for navigation in the rubber plantation.

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