Localization of Agricultural Vehicle Using Landmarks Based on Omni-directional Vision

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Abstract. This paper describes a system would be for localization of agricultural vehicle in farm fields using landmarks based on Omni-directional vision. The approach set four red artificial landmarks as rectangle in the corner of one farm field. The algorithm extracted red pixel points as a small area, calculated average point as landmarks and estimated four angle measurements using Omni-directional image. Location of vehicle was estimated by the center of gravity of four intersections of four arcs according to geometric transformation of four angles among four landmarks. Experimental results show that the maximum and mean errors were lower than common GPS and the tracking result is better. In conclusion, the algorithm and the method are feasible and could substitute for GPS to satisfy for navigation system of agricultural vehicle in future.

Keywords: Omni-directional vision, navigation system, localization, agricultural vehicle

1. Introduction

Agricultural automation has become a major issue in recent years. The development of autonomous navigation systems for agricultural vehicles is regarded as one of development of precision agriculture and a promising alternative to cope with the dwindling farming labor force, in addition to the quest for higher production efficiency and safer operation. In previous studies of navigation systems for agricultural vehicles, various methods such as radar positioning [1], laser positioning [2], Ultrasound [3] and machine vision [4] were applied. The most popular method has been GPS [5]. Real-Time Kinematic (RTK) GPS can provide with a 1 cm accuracy, consistent with guidance applications, (Differential GPS can only provide with a 50cm accuracy). Nevertheless this sensor has also some limitations. First, the accuracy depends on the position of the satellites. In urban environments, especially in narrow streets called urban canyons, buildings can occult the microwaves from satellites. In that case the accuracy drops considerably. To overcome this occultation, the fusion with odometry must also be used. Secondly, a kinematic GPS is very expensive.

Recently, Omni-directional vision sensors are very attractive for autonomous navigation system [6]. The camera and the mirror are mounted on the top of the mobile robot's platform. The images grabbed from the sensor are orthographic projections of the ground plane. The images (obtained without rotating the robot) are 360 degree view of the environment and not sensitive to wheel slippage and small vibrations. This low cost sensing device provides enough information for our navigation system. Although it is not straightforward to obtain distance estimations from an Omni-directional image due to shape of the mirror, the apparent angles of objects from the robot are relatively accurate and easy to derive from the image.

There are many approaches using landmarks based on Omni-directional vision sensors in robot [7, 8]. The key advantage of these approaches is that the robot has a panoramic view of its environment, which makes it possible to create features that are invariant to the robot's orientation. Marques and Lima [9] detect field lines using the Hough transform and correlate them with the field model to estimate the robot position. Jang et al. [10] present a simple artificial landmark model and a tracking algorithm for indoor mobile robots. However, there have been few studies on localization in farm fields.

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We propose a system would be for localization of agricultural vehicle in farm fields using landmarks based on Omni-directional vision. Section 2 introduces our proposed approach principle and calculation methods, and describes how we process the Omni-directional image to obtain landmarks information. Section 3 we present the experimental tests performed on the level ground indoor and outdoor. A detailed analysis of the performance and robustness of the localization system is presented. Finally, our conclusions are drawn and future works are considered.

2. Proposed approach

In this work, the extraction of landmarks is the first step and very pivotal to realize localization. In farm fields, the same crop shows the homologous color, so we almost can't use natural landmarks. The approach sets four red artificial landmarks as known width and length rectangle on the corner of one farm field. We developed a new algorithm to extract pixel points as a small area, average point of the extracted small area as landmark position. The distortions due to the mirror reflection cause nonlinear changes on the projected image. The linear calculation methods cannot appropriately cope with such distortions. Hence, we estimated four angle measurements using Omni-directional image. Location of vehicle was estimated by the centre of gravity of four intersections of four arcs according to geometric transformation of four angles among four landmarks. The oriented direction was easily defined and the estimation localization can be taken as the basic localization to decreasing accumulative error.

2.1. Extraction of landmarks

Fig.1 shows an example of the captured images captured by Omni-directional camera.

The representations of landmarks were detected as red sections in the images. We defined the red color level as RCL, the maximum points of RCL as R_{max} and the red level of extracted landmark as Rs. Here, RCL was estimated for every pixel in the images by the Equation (1) [11].
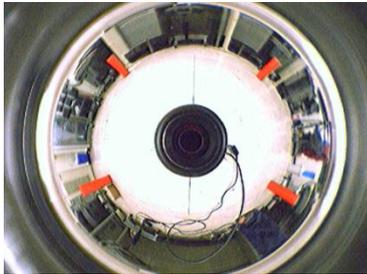
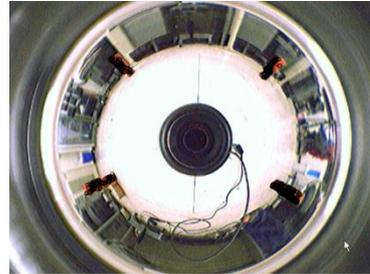$$RCL = R - (B + G)/2 - |B - G| \tag{1}$$

Fig. 1: Omni-directional image.   Fig. 2: Landmarks extraction after image processing.

Where, R, G and B represent red, green and blue intensities, respectively. The RCL of pixels is not less than value ($Rmax$-60) will be selected out to form a small area, selected points expressed as $Ri(i = 1,2,3....n)$. The landmark's position can be estimated by the (2) in the small area.

$$Rs = \frac{\sum_{i=1}^{n} R_i}{n} \tag{2}$$

Fig.2 shows the results of landmarks after image processing. Fig. 3 shows landmarks will become a point and the direction angles of the four landmarks were estimated $\theta_i(i = 1,2,3,4)$.
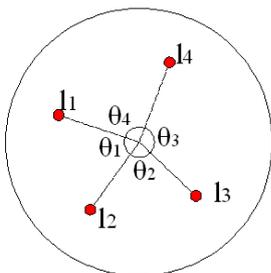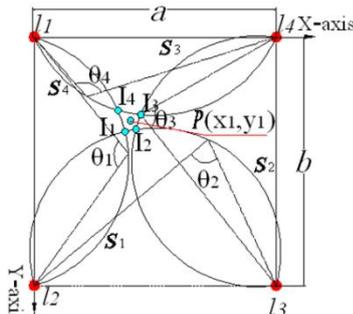

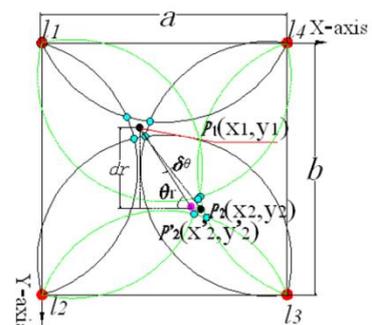Fig. 3: Directional angles.   Fig. 4: Position determination.   Fig. 5: Orientation angle and distance.

2.2. Estimating position n and calculating orientation

We can draw the circular arcs Si ($i=1,2,3,4$) based on the value of direction angles as shown in Fig. 4. If there is on error, all four arcs should intercross at one point, but in practical conditions, several different intersections would be formed by measurement errors. In our system, we determine the estimated position $P(x_1,y_1)$ by the center of gravity of the four intersections I_i ($i=1,2,3,4$) intercrossed by the arcs. We assume the coordinate system of the farm field is represented by X and Y axis and define the length of farm field as b and the width of farm field as a; According to geometrical relation, we get (3):

$$\begin{cases} \tan\theta_1 = {ax_{I1}}\big/{(x_{I1}^2 + y_{I1}^2 - ay_{I1})} \\ \tan\theta_2 = {by_{I1}}\big/{(x_{I1}^2 + y_{I1}^2 - bx_{I1})} \end{cases} \tag{3}$$

If, $\dfrac{b}{\tan\theta_2} - a \neq 0$, we can get the following result (4).

$$\begin{cases} x_{I1} = \dfrac{a(c + 1\big/\tan\theta_1)}{1 + C^2} \\ y_{I1} = \dfrac{ac(c + 1\big/\tan\theta_1)}{1 + C^2} \end{cases} \tag{4}$$

Here,

$$C = \dfrac{a\big/\tan\theta_1 - b}{b\big/\tan\theta_2 - a}$$

If, $\dfrac{b}{\tan\theta_2} - a = 0$ and $b - \dfrac{a}{\tan\theta_1} = 0$, $x_{I1} = 0$ and $y_{I1} = 0$.

If, $\dfrac{b}{\tan\theta_2} - a = 0$ and $b - \dfrac{a}{\tan\theta_1} \neq 0$, $x_{I1} = 0$ and $y_{I1} = a$.

Similarity, we can get X axis and Y axis absolute value about the four intersections I_i ($i=1,2,3,4$).Then, the absolute coordinate values of the estimated position were calculated by (5).

$$\begin{cases} x_1 = {(x_{I1} + x_{I2} + x_{I3} + x_{I4})}\big/{4} \\ y_1 = {(y_{I1} + y_{I2} + y_{I3} + y_{I4})}\big/{4} \end{cases} \tag{5}$$

After one position of camera is estimated, the system should know its orientation angel and distance of vehicle from one point to next point. In Fig. 5, $P_2(x_2,y_2)$ is the next commanded tracking position relative to the system position $P_1(x_1,y_1)$; $P'_2(x'_2,y'_2)$ is the estimated position relative to commanded position by system program. The orientation angle defined as θ_r, the orientation distance dr and the orientation angle error δ_θ. We calculate them by (6) and (7), respectively.

$$\theta_r = ant\left(\frac{y_2 - y_1}{x_2 - x_1}\right) \tag{6}$$

$$d_r = |y_2 - y_1| \tag{7}$$

3. Experiment result and discussion

The purpose of experiments is to prove the feasibility of our proposed method, analyze the cause of error and its evaluation.

3.1. About indoor experiment

In the indoor experiments, we have used an Omni-direction camera (SOIOS 55-CAM), shown in Fig. 6, the resolution is 640×480; the landmarks set at the four corners of a 120cm x 120cm square area on the cement horizontal floor in our laboratory in the light lamp; the diameter of landmark was about 7cm.
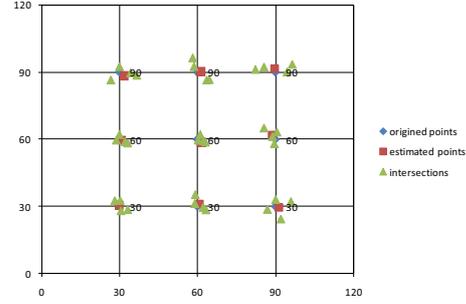
Fig.6: Indoor experimental device.

Fig.7: Results depicted in the map.

We have selected 9 positions to test the estimated results from image one by one. Fig. 7 shows that the estimated points are shown as rectangles (▪) (average of four intersections) of each position almost cover the originated point are shown as diamonds (♦). It also shows that some of the intersections are shown as triangles (▲) are deviated from the originated points a little.

In the indoor experiment, Tab.1 shows that the maximum errors of X axis, Y axis are 1.73cm and 1.85cm respectively. The maximum error of distance between originated points and estimated points is 2.59cm.The mean error is less. Compared with common GPS, the results is better similar to RTK GPS.

Tab. 1: Errors of X, Y and distance (D) about indoor experiment

	Mean error	Max error	Min error
X(cm)	1.00	1.73	0.13
Y(cm)	1.02	1.85	0.40
D(cm)	1.31	2.59	0.09

3.2. About outdoor experiment

In the outdoor experiments, we use an integrated type Omni-directional camera (Vstone, VS-C-300-TK), shown in Fig. 8. And the resolution is 1024×1058. The landmarks were set at the four corners of a 24m x 24m square area and the bottom diameter of landmark was about 23cm.In outdoor experiments were carried out on a flat and horizontal ground.

We have done a tracking experiment to test the system. We selected 25 points formed a rectangle on a flat and horizontal ground. Fig. 9 has shown the tracking results. The original route is shown as points (▪) and estimated tracking is shown as points (∗).
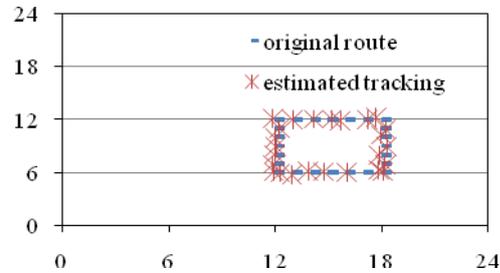

Fig. 8: Outdoor experimental device.

Fig. 9: Original route and estimated tracking.

Tab.2 has shown that the tracking results. The maximum error of X axis is 31cm and the maximum error of Y axis is 32cm. The maximum error of distance (D) between originated points and estimated points is 29.25cm. The maximum error of orientation angle (δ_θ) is 3.33 degree. The maximum error of orientation distance (dr) is 32cm. The mean error is relatively lower, e.g. the mean error of distance between originated points and estimated points is 3cm. As we can see, although the results of our system are worse than the results of RTK GPS, our system mean error is less than GPS.

Tab. 2: Errors of X, Y, orientation angle δ_θ and distance (D) about outdoor experiment

	Mean error	Max error	Min error
X(cm)	9.00	31.00	1.00
Y (cm)	6.33	32.00	1.00
D(cm)	3.00	29.25	0.25
(δ_θ°)	0.93	3.33	0.10
dr (cm)	6.33	32.00	1.00

We can't compare the error between indoor experiment and outdoor experiment, here. Because the system will applied for field and we will use the maximum distance relative error (*DMR*) to area of field. We can calculate it by the formula ((maximum error/area) * 100 %). The *DMR* of indoor experiment is 18% and the *DMR* of outdoor experiment is 5.13%. The *DMR* is relative different. This error is due to several reasons, like, the resolutions of camera are different for different extraction of landmarks and the landmarks is different themselves because the area is bigger and the landmarks are too small to take image. Secondly, our algorithm of selecting some red level points and of missing some red level points according to the same balance equation maybe cause some errors and there are some measurement errors.

4. Conclusion and future work

We can conclude the algorithm and the method presented here that using for agricultural vehicle localization are feasible and can successfully decide absolute localization more accurately with four landmarks. Using our algorithm, the red landmark can be detected distinctly and its position can be estimated. Experimental results show that the errors are lower and the tracking result is better. The minimum errors are similar results, but the maximum errors are different too much for indoor and outdoor experiments. Because the area is bigger to increase the measurement errors and the sunlight maybe cause the blurry of images and difficult to define the landmarks accurately. But the maximum distance relative error (*DMR*) to area of field of indoor experiment is 18% and the *DMR* of outdoor experiment is 5.13%. The key reason is detection errors of landmark and measurement errors. Using two different cameras with different resolution about indoor experiment and outdoor experiment also cause some errors. In the future, we will use the same camera to find the correlation about camera and landmark detection, considering camera height and landmark's size and color. And will improve our algorithm to detect landmarks. In real-time practice, there are some problems about our algorithm calculating speed. Secondly, we should consider agricultural vehicle will work on the slope and compensate the errors when the camera is inclined. In conclusion, we can know, if the resolution of Omni-directional vision is enough to take images of landmarks, the proposed system will substitute for GPS to use in agricultural vehicle navigation.

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