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Vision-based Pest Detection and Automatic Spray of Greenhouse Plant

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***Abstract-* This paper proposes a new method of pest detection and positioning based on binocular stereo to get the location information of pest, which is used for guiding the robot to spray the pesticides automatically. The production of agricultural cultivation in greenhouse requires of big quantities of pesticides for pest control. Pesticides application is a major component of plant production costs in greenhouse, and the excess in their applications have a great negative impact on the environment. A pesticide application is ideal if the spraying coverage is presented as evenly distributed over the whole plant canopy and, if the product application is correctly adjusted for minimizing the losses towards the soil or the environment. In this approach, the difference of color features between pest and plant leaves is extracted by the image segmentation to identify pest. According to the results of image segmentation and binocular stereo vision technique, the 3D position of the pest has been obtained. In the process of position locating, centroid-matching technique is adopted to displace the common object-matching. The formula based on binocular stereo vision to measure distance is revised, additionally.**

Keywords: binocular stereo, depth measurement, automatic spray

I. Introduction

In the past decades, greenhouse dedicated to agricultural plants production has a rapid development of quantity. A lot of researches have been done on greenhouse plants and more generally on protected plants to control pests and harvest fruits. In order to save the labor and protect health of human, domestic and foreign researchers have been researched on exploit the robot used for harvesting fruits [1][2] and spraying pesticides to plants in greenhouse diffusely.

Before robot harvesting fruits or spraying pesticides, the location of target is necessary. Stereo vision improves approaches by adding the third dimension depth, to attain a more accurate localization of objects within the sensed scene. According to apple in the three-dimensional image parallax, a given three-dimensional space divided into a number of equidistant space, is researched by Takahashi [3]. The computer vision system to obtain tomato RGB image is converted into HIS image, according to the weight of the gray-scale distribution of H the ripe tomato region is partitioned with threshold method to identification of ripe tomato, researched by Wenjie Zhao [4].

In this paper, a study of 3D information of pest detection is presented. Red color pest models are given and pasted on plant leaves as the target for detection, based on the triangulation of binocular vision, it is 3D position could be calculated by matching the correspondence centroid point of the given pest model which segmented from the HSV color space. Through this method, the pest could be identified from the background and then the location information of pests will be measured by using Area-based matching method. The experiments show that, the proposed method could not only identify and locate the targets fast, also have accurate measurement results. This method can be used in the greenhouse robot for controlling pests automatically in greenhouse, the requirement of labors is reduced and work efficiency will be improved greatly.

In section 2, we closely segment images using the calibrated camera, eliminate noise, and match area-based to measure the depth of target. In section 3, we describe how to construct binocular stereo vision system by using a single camera. In section 4, we analyze the experiment data. Finally, in section 5, we attach our acknowledgement.

II. MATERIAL AND METHODS

A. Camera Calibration

Camera calibration has always been an essential component of photogrammetric measurement. Self-calibration has become an integral and applied operation in photogrammetric triangulation nowadays, especially for high-accuracy close-range measurement.

The two extremes of such calibration approaches are the so-called photogrammetric calibration and pure auto calibration, whereas some other methods exist.

Traditionally the methods of calibration were used to resolve a pack of non-linear equations based on triangle measurement principle. The calibration procedure requires a set of at least 3 image pairs of a planar checkerboard target, so that it can find the image features in each of the image pairs, and then processes calibration calculation.

In our work, camera calibrated using the method which proposed by Zhang zhengyou[5], in order to obtain the camera intrinsic parameters and external parameters.

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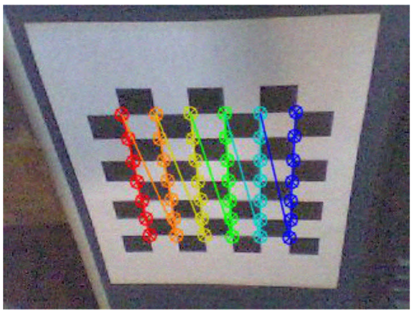
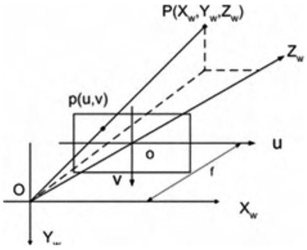


(a)



(b)

Fig.1. (a) Chess for calibration. (b) Single camera model .

The equation of coordinates transformation is shown as follows.

$$\lambda\begin{bmatrix}u\\v\\1\end{bmatrix}=\begin{bmatrix}\frac{1}{k} & 0 & u_0\\ 0 & \frac{1}{l} & v_0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}f & 0 & 0 & 0\\ 0 & f & 0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}X_c\\Y_c\\Z_c\\1\end{bmatrix}$$

$$\begin{bmatrix}X_c\\Y_c\\Z_c\\1\end{bmatrix}=\begin{bmatrix}R_{3\times3} & t_{3\times3}\\ 0^T & 1\end{bmatrix}\begin{bmatrix}X_w\\Y_w\\Z_w\\1\end{bmatrix} \tag{1}$$

Where $k \times l$ is the physical size of a pixel. λ is the proportional coefficient in the camera model. f is the camera focus length. u, v is image coordination on x and y axis respectively. These parameters are obtained by the camera calibration. And the world coordination and the camera coordination are denoted respectively by $[X_w, Y_w, Z_w]^T$ and $[X_c, Y_c, Z_c]^T$. The coordinate transformation, a rotation matrix $R_{3\times3}$ and a translation matrix $t_{3\times3}$ denote the rotation and translation of the two coordinates.

B. Gaussian smoothing

There is noise during the process of image transmission. Therefore, a filter is used to eliminate noise in order to process more accurately.

$$G(x,y)=e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{2}$$

where σ is the standard deviation and the center of the Gaussian is (0, 0).

C. Image Segmentation

The quality of image segmentation is directly related to the quality of the final results of the analysis.

Targets are identified from images accurately, which is the crucial step in the robot stereo vision system, and target identification is the essence of image segmentation.

Since the selection of color space for image processing is essential, we selected the HSV (Hue Saturation Value) color space in this paper. RGB color space is selected frequently in color space for equipment, but there is high correlation between R, G, and B. If use the value directly, we often unable to get satisfactory results. In order to reduce the correlation between R, G, and B, we often need to transform RGB color space to HSV color space. HSV color space intuitive and in line with the human visual characteristics, these features make the HSV model is well suited on human visual characteristics of color image processing. The formulas of conversion from RGB to HSV are shown as follows.

$$H=\begin{cases}\arccos\left\{\dfrac{(R-G)+(R)}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}, B\le G\\[2ex] 2\pi-\arccos\left\{\dfrac{(R-G)+(R)}{2\sqrt{(R-G)^2+(R-B)(G-B)}}\right\}, B>G\end{cases} \tag{3}$$

$$S=\frac{\max(R,G,B)-\min(R,G,B)}{\max(R+G+B)} \tag{4}$$

$$V=\frac{\max(R,G,B)}{255} \tag{5}$$

According to the graphical depiction of HSV shown as Fig.2 and by many experiments, the red hue component intensity range can be estimated. The intensity range is 0 to 30 and 350 to 360.

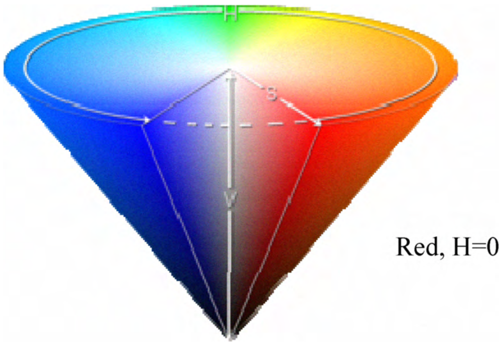


Fig.2. Graphic representation of HSV.

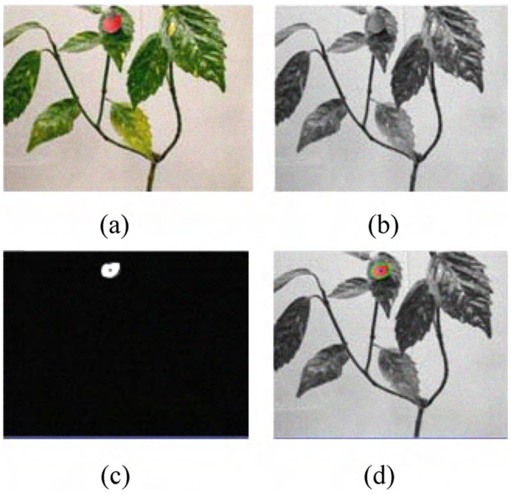


Fig.3. (a) Original images obtained by camera.
(b) Gray-scale adjust.
(c) Image segmentation and area-based matching.
(d) The results of Figure.

D. Center of the enclosing circle

In our experiment, the actual position of the pest is assumed to be the center point of pest model. In this paper, function cvMinEnclosingCircle of OpenCV class is used to obtain the actual location. The result is same as Fig.3. (d).

The function cvMinEnclosingCircle finds the minimal circumscribed circle for 2D point set using iterative algorithm. It returns nonzero if the resultant circle contains all the input points and zero otherwise

E. Area-based matching

Approximate depth information of pest model can be estimated with centroid-matching, however, relying on one point could be too sensitive to noise, and the exact spraying position still has not been found. In order to make this processing more robust, area-based matching is used to locate surface points. It is feasible to compute the length and width of the rectangle bounding the pest model in the result of recognition.

The overall stereo algorithm consists of four main steps. The input images are normalized by subtraction of the mean values of the intensities computed in a small window centered at each pixel [6]. This allows for compensating for different settings of the cameras and or different photometric conditions. Moreover, since matching turns out to be highly unreliable when dealing with poorly textured areas, the variance of the intensities is calculated at each pixel considering a window of the same size as that used to obtain the means. This information is used to detect regions with lack of texture. The normalized images are matched according to the matching approach, which is independent of the error (similarity) function. Currently, we use the method called Sum of Squared Differences (SSD). The reliability of the matches provided by the basic matching core is improved by means of the “distinctiveness” and “sharpness” tests. In addition, this step uses the variance map computed in the pre-processing step to reject the matches found in poorly textured areas. The final step performs sub-pixel refinement of disparities.

There are some methods to calculate the difference between two windows in left and right image, such as Sum of squared differences (SSD), Sum of absolute differences (SAD), Normalize cross-correlation (NCC) and so on. In this paper we use the method of SSD, as expressed by

$$SSD_{(x,y,d)} = \sum_{i=1}^{n}\sum_{j=1}^{m}[L(x+i,y+j)-R(x+i+d,y+j)]^2 \tag{6}$$

Where, L(x, y) and R(x, y) are respectively the grey of points(x, y) in left and right image, n and m are the width and height of window, and d is the disparity. Changing the format of (6), we can get that

$$SSD_{(x,y,d)} = \sum_{i=1}^{n}\sum_{j=1}^{m}[L(x+i,y+j)]^2$$
$$-2\sum_{i=1}^{n}\sum_{j=1}^{m}[L(x+i,y+j)R(x+i+d,y+j)]+$$
$$\sum_{i=1}^{n}\sum_{j=1}^{m}[R(x+i+d,y+j)]^2 \tag{7}$$

The first item is the energy of the template window, a constant, while the third one is the energy of target window in right image, which changes slowly as i and j. The second one is the covariance of template window and target window. What do we care for is the state of every item when getting correspondence point, obviously, the second item will be maximum. So (8) can be normalized

$$R_{(x,y,d)} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m}[L(x+i,y+j)\times R(x+i+d,y+j)]}{\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}[L(x+i,y+j)]^2}\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}[R(x+i+d,y+j)]^2}} \quad (8)$$

As known, $0 < R_{(x,y,d)} < 1$ .The reasons that we use R not SSD are: R can't be influenced by different brightness of left and right image.

F. Depth measurement

Through the steps which proposed above, we can get the region where pest is. Assuming center point of the region for the actual location of pest, stereovision checks the disparities between two images and the depth information of pest could be calculated with triangulation.

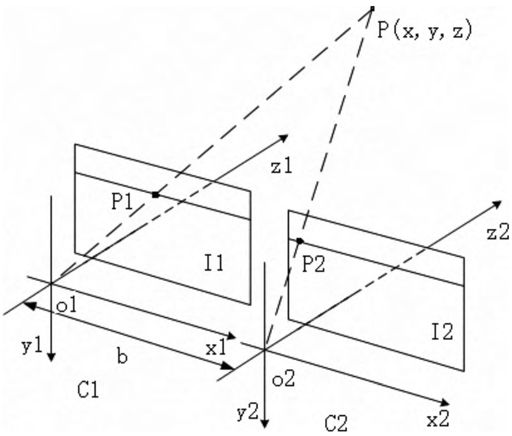


Fig.4. Binocular stereo vision system model.

Fig.5 illustrates the geometry model involved in depth detection with triangle theory. The distance between cameras is defined as baseline and represented by b. The focal length is f, and R represents the range or depth to the sensed object. X_L gives the position in pixels (image domain) of the object in left image whereas X_R gives the position, also in pixels, of the same point in right image. So the disparity is defined as

$$d = | X_L - X_R | ,$$

$$| X_L - X_R | = |u_L - u_R| E \quad (9)$$

E is the size of one pixel on the CCD.

As stated in this equation, the depth and disparity are inversely proportional

$$d = \frac{b \cdot f}{D} \quad (10)$$

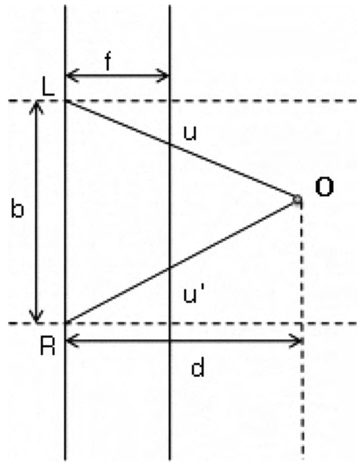


Fig.5. Triangulation to obtain depth information.

III. EXPERIMENT AND AUTOMATIC SPRAY

The experiment uses the robot made by Pusan University Intelligent Robot Laboratory, as shown in Figure6.

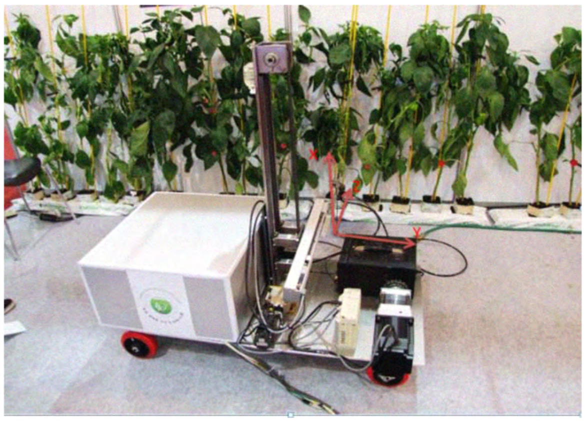


Fig.6. Robot used in experiment.

Camera and nozzle are installed on the end of robot arm. During moving, when robot finds a plant, robot stop moving and the arm inspection to the plant from bottom to top. During up exercise, to the distance b for the interval set stop point in order to constitute binocular stereo vision system using one camera. Using the method introduced in part2 and part3, the depth information of pest could be calculated. And then through the depth of information obtained, robot can control arm how much distance had extended to sure the pest in the scope of the spray nozzle.

A DSP board is used to control the spray nozzle, transfer data by RS-232-C between chip and computer fixed at the robot. And the robot control program is developed in Visual C++ 6.0 on windows system.

IV. RESULTS AND ANALYSIS

Experiment data that are corrected based on different depth are analyzed.

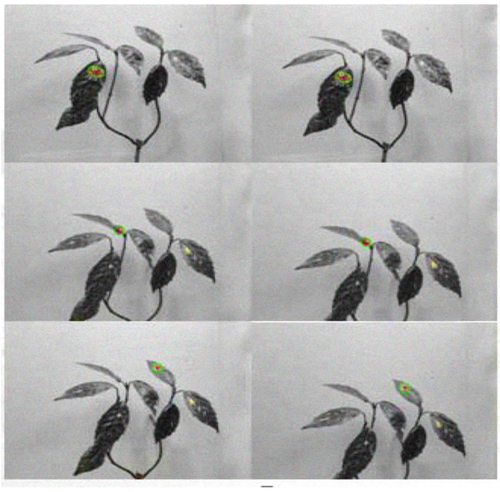


Fig.7. Images obtained by binocular stereo vision with different depth information.

TABLE I
COMPARISON BEWEEN MEASURED DISTANCE AND ACTUAL DISTANCE

	u_L (pixel)	u_R (pixel)	Actual value(mm)	Measured value(mm)
1	360.768	404.108	455	453.96
2	162.515	263.365	316	314.77
3	392.221	353.029	488	502.00
4	162.515	228.676	316	319.87

In the Table I, the error focused on the range of 20mm when the depth measure is less than range of 500mm. There is error on measuring depth of pest, but it is not too big, and fully to sure the pest in the scope of the spray nozzle.

Data are shown in Figure8 in order to describe the result of experiment visually.

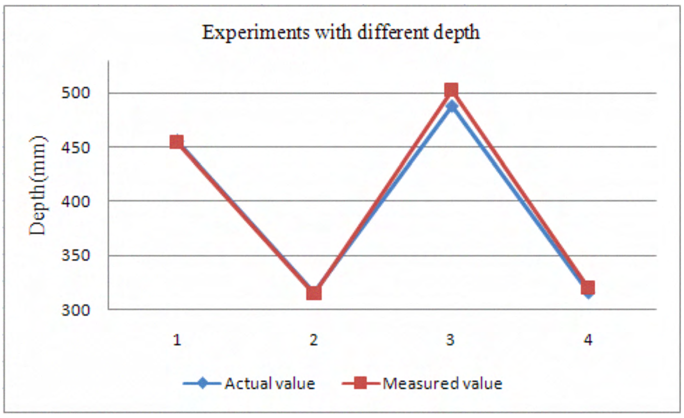


Fig.8. Comparisons between measured and actual distance.

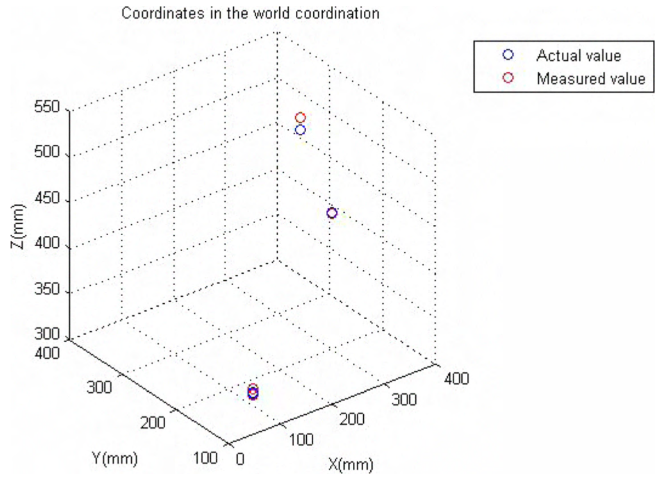


Fig.9. Actual points and measured points in the world coordination.

V. CONCLUSIONS

In this paper, a depth measurement method for detecting pests on leaves is proposed. And it provides pests position for automatically spraying pesticide on the leaves where the pest model pasted on. The depth measurement is based on a binocular stereo vision system which is implemented by a single camera. The experimental results show that the measured depth is accurate and measurement error is acceptable for controlling the pests. And also the results indicate that the proposed method of working is reliable for measuring depth. But the illumination conditions make noises and the size and color of pest model are the reasons that could lead to the measurement errors. The protective color of pest is considered in this study, it could be the future research.

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