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THE DEVELOPMENT OF A SINGLE CAMERA STEREO VISION SYSTEM FOR STARFRUIT INSPECTION SYSTEM

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ABSTRACT

In this paper, we proposed the application of monocular stereo vision system which specific for starfruit quality inspection purpose. The system only uses one camera and a moving conveyor belt for producing a stereo pairs in generating the depth value of the starfruit. Since most of the fruit quality inspection only involve in one camera and a conveyor belt system for checking the quality, the proposed system can be easy to be apply in existing machine vision system. The single camera setup also made the camera calibration system become simple compare to binocular stereo vision system. With only taken two images on moving object, the depth value can be obtained successfully.

Keywords: stereo matching, camera calibration, fruit inspection.

INTRODUCTION

Implementation of starfruit quality evaluation system has been done by some researchers under machine vision. The starfruit quality has been evaluated and classified based on the colour, shape, maturity and defects on the fruit.

In [1], starfruit quality has been done based on the colour and shape. The maturity of starfruit is determined using linear discrimination analysis and multi-layer perceptron neural network to classify it into unripe, underripe, ripe and overripe category in HIS colour space. Besides that, three shape categories as well-formed, slightly deformed and seriously deformed have been detected through Fourier transform.

Starfruit shape defect estimation have been proposed in [2] by using concave and convex area along a closed curve. The starfruit shape defect along the ridges can be determined through modified convex hull algorithm.

Segmentation of starfruit is performed in [3] based on YCbCr colour space. The region of interest for classification can be done by using a fixed threshold value for the Cb component. In [4], a real-time system for starfruit colour maturity inspection is developed using YCbCr colour space. Six maturity indices have been successfully categories by obtained the value of Cr component.

Starfruit maturity classification algorithm has been implementing into an embedded real-time system in [5]. The system is using Field Programmable Gate Array (FPGA) for process the 2 colour component for classification purpose. In [6], machine vision for starfruit inspection setup framework for image acquisition has been proposed. The setup can be use to capture the starfruit image from three sides to obtain the overall shape by using single camera and mirror.

Most of the research work done in starfruit inspection is only capture an image of starfruit in one angle only. The image taken only from the top of view and assume it is flat surface. This will lead to surface limitation problem and generate an inaccurate defect detection results. In previous work, no complete system has been used in evaluation because it is based on single features such as colour or shape only. In order to improve the system, depth can be used as a new feature.

Depth reconstruction is an important research area in machine vision system, which can generate 3D information from 2D images. Stereo vision is one of the major methods to compute depth among the others methods due to its simple setup which require only conventional camera. Stereo vision method is usually referring to binocular stereo vision, which requires two camera separated by a baseline to capture the image of same scene in one time. The disparity or pixel differences between correspond points in two images will be use to estimate depth value based on triangulation.

In binocular stereo vision system, finding corresponding points to be match is the main issue for estimate the depth. The calibration for both cameras also is one of the problems need to be solve. In order to solve some problems occur in binocular stereo vision, monocular stereo vision has been introduced.

Monocular stereo vision only uses single camera in order to estimate the scene depth. Single camera can be easy to calibrate and less computational cost compare to binocular stereo vision.

Lee and Kweon have proposed biprism-stereo camera system where only using one camera and a biprism placed in front of the camera. By using birprism, stereo pair images are formed at left and right halves of the camera sensor [7].

Gao and Ahuja used a single camera and a transparent plate which placed in front of camera and

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rotates on camera's optical axis to estimate depth. A sequence of images with different rotational angle is captured to store large number of stereo pair images [8].

Nene and Nayar has proposed four stereo systems that using single camera which pointed towards planar, ellipsoidal, hyperboloidal and paraboloidal mirrors [9]. Yi and Ahuja has developed omnidirectional stereo imaging system that uses a concave lens and convex mirror for generate a stereo pair of images on the sensor of a conventional camera [10].

Lin and Subbarao has introduced a rotational stereo technique for 3D model reconstruction by acquired multiple base-angle images from single camera. Multiple base-angle images are captured by rotating the stage with different angles [11]. Xu, Wang and Zhang have proposed a method to recover the depth by obtained the monocular disparity from bifocus images. The stereo disparity is the results from lenses separation during imaging [12].

Xia, Li, Chon and Lee have proposed a binocular stereo vision system using a single camera which can move up and down on a vertical arm of the robot [13]. Tsai and Katsaggelos have introduced a sequential 3D-based scene description technique. Multiple small baseline 3D scene descriptions from a single moving camera or an array of cameras are used to sequentially construct a large baseline 3D scene description while maintaining the field of view of a small baseline system [14].

From the previous work, monocular stereo vision can reduce the difficulty of calibration problem occur in binocular stereo vision system. Although the calibration on camera become easier in monocular stereo vision system, but it still need extra equipment which required extra measurement or calibration. This will make the calibration process on extra equipment become more complex compare to binocular stereo vision system.

In this paper, we proposed a simple and easy monocular stereo vision system which only required only one camera and a conveyor belt system. The stereo image pairs can be generated by taking two images in different position on moving conveyor belt. Depth value of the starfruit can be obtained by calculating the disparity of the corresponding points in the stereo image pairs.

METHODOLOGY

PROPOSED SINGLE CAMERA STEREO VISION

Camera setup

Figure-1 shows the camera setup of proposed single camera stereo vision system. The setup only involved a single camera which mounts at the top of the conveyor belt which is the basic setup for most of the machine vision system. The stereo image pairs for generating the depth value will be taken by moving the targeted object, starfruit using conveyor belt from one position to another position in one direction.

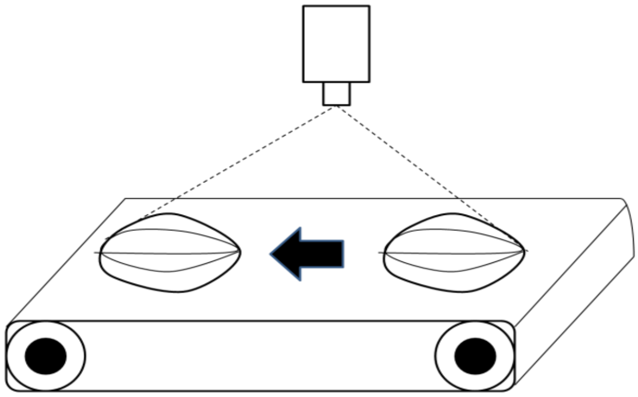

Figure-1. A camera setup for single camera stereo vision system.

Basic principle

The proposed single camera stereo vision system geometry view is illustrated in Figure-2. Two images for stereo image pairs can be generated from the two positions by moving the targeted object using conveyor belt to move from m1 to m2. From Figure-2, f is the focal length of the camera, a is ratio of the sensor size with image resolution, d is the disparity of corresponding points between two images, T is the baseline or distance between the first and second images taken, and Z is the depth value or distance from the target object to the lens.

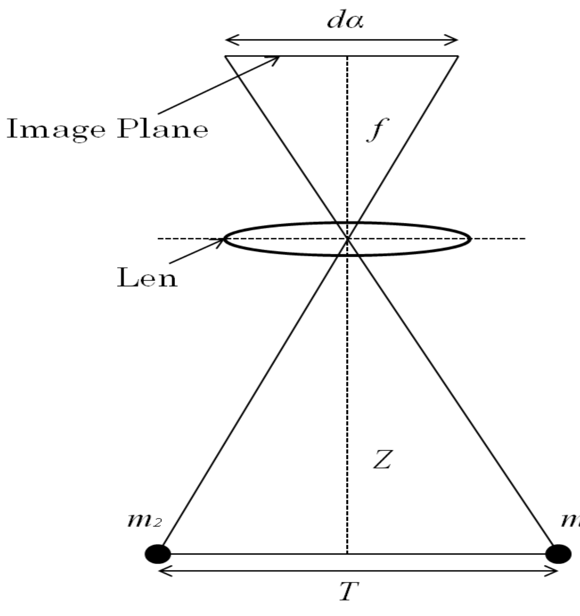

Figure-2. The geometry of single camera stereo vision system.

The depth value can be computed using the equation (2) by measure the baseline and determine the disparity of corresponding points.

$$\frac{Z}{T} = \frac{f}{d\alpha} \tag{1}$$

$$Z = \frac{Tf}{d\alpha} \quad (2)$$

Depth resolution(r)

By definition, depth resolution is how accurate the depth value in unit of mm on 1 pixel difference of the disparity. In order to find the depth value for the starfruit which has the complex shape and has a small changing in shape of the ridges, high depth resolution is needed. The depth resolution for starfruit inspection purpose should be accurate in term of 1mm.

The basic rule for determine the depth resolution in single camera stereo vision system can be derived as follows. The depth value for depth resolution can be obtained using equation (3) or (4)

$$Z_r = Z - r \quad (3)$$

$$Z_r = \frac{Tf}{d_r\alpha} \quad (4)$$

The equation (3) can be derived to generate equation (5) which the disparity of the corresponding points is 1-pixel value

$$Z - Z_r = Z - (Z - r) = r \quad (5)$$

$$d_r - d = 1 \quad (6)$$

Thus, we can define depth resolution as:

$$r = \frac{Tf}{d\alpha} - \frac{Tf}{d_r\alpha} \quad (7)$$

$$r = \frac{Tf}{\alpha}\left(\frac{1}{d(d+1)}\right) \quad (8)$$

From equation (8), we can find suitable Z value which wills fulfill the depth resolution requirement as below.

$$r = \frac{Tf}{\alpha}\left(\frac{1}{d(d+1)}\right)$$
$$r = \frac{Tf}{\alpha d}\left(\frac{1}{d+1}\right)$$
$$r = Z\left(\frac{1}{d+1}\right) \quad (9)$$

$$Z = r(d+1) \quad (10)$$

From equation (10), the small value of one can be ignored and an approximate equation as:

$$Z = rd \quad (11)$$

Last, the depth resolution rule is expressed as:

$$r = \frac{Z}{d} \quad (12)$$

Based on this rule, calibration to the single camera stereo vision can be done by computing the Z value which will affect the result measurement of the accuracy at desired depth resolution.
Due to the approximation of:

$$d + 1 \approx d \quad (13)$$

Equation (8) can be expressed as:

$$r = \frac{Tf}{\alpha}\left(\frac{1}{d^2}\right) \quad (14)$$

Thus, the disparity also can be calculate using equation (15)

$$d = \sqrt{\frac{Tf}{r\alpha}} \quad (15)$$

The relationship between the depth resolution and the depth value can be expressed as:

$$Z = rd = r\sqrt{\frac{Tf}{r\alpha}} \quad (16)$$

Starfruit inspection system setup

The actual hardware implementation of the theoretical description can be seen in Figure-3 and Figure-4. Figure-3 shows the three dimensional drawing of the starfruit inspection system which consists of several main components: camera holder which holds the camera for image acquisition; lamp to provide even illumination for image acquisition; and conveyor to move the starfruit in order to obtain accurate displacement for two images.

Figure-4 shows the front view of the starfruit inspection system which clearly shows the exact location of the lamp, camera holder and the conveyor belt.

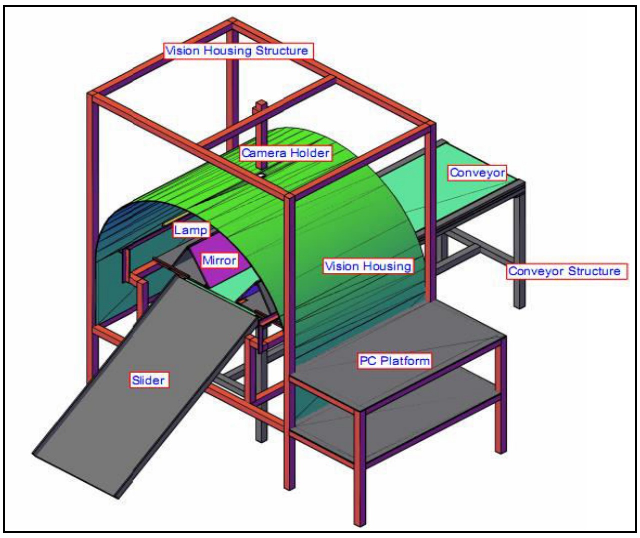

Figure-3. The 3D drawing of the star fruit inspection system.

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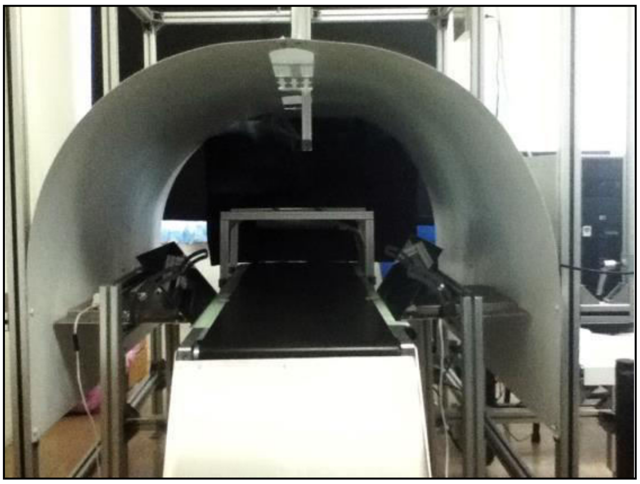

Figure-4. The actual hardware of the star fruit inspection system

EXPERIMENTAL RESULT

In order to test the proposed system, some images is taken for calculate the depth value. In the experiment, the Ganz camera has been used for captured the stereo image pairs. The resolution of the image is 384 x 288. The target objects for testing purpose were small boxes with different height which can generate different depth value. The background of the image is blank without anything.

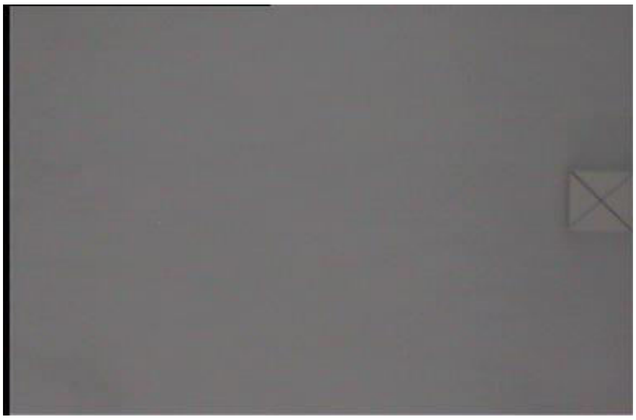

Figure-5. First image before the object is moving.

Figure-6. Second image after the object is moving.

The stereo image pairs are generated by taken the first image before the conveyor belt is moving as illustrated in Figure-5 and second image after the object is moving to the left side by conveyor belt as shows in Figure-6. The baseline of the image is measure manually using a ruler. The marking on the box was used as the corresponding point for calculating the disparity. The depth value can be obtained by using the equation (2). The actual depth value or the heights of the boxes were measured by using a digital caliper.

There were five boxes as the targeted object in this experiment. Table-1 presented the results of the depth value obtained by calculation, measurement and the relative error.

Table-1. Depth value for five different boxes (in mm).

Box	Actual Value	Calculated Value	Relative Error
1	1.02	1.45	0.42
2	2.12	1.41	0.33
3	3.16	2.43	0.23
4	4.37	4.45	0.02
5	5.37	5.45	0.01

From the result of the Table-1, the relative error is reducing when the depth value of the boxes is increasing. This means the system can provide precise result for higher depth value. The bigger relative error was occurred because of lower resolution image which cannot provide higher pixel value difference. The lower baseline which generates the lower value of disparity also is another cause that affected experimental result. High resolution and narrow focal length of lens can be used to solve these problems.

Then, the experiment is done using an actual starfruit inspection system setup as shown in Figure-3 and Figure-4. Images obtained from the inspection system as shown in Figure-7. Several points of the starfruit are taken in order to measure the relative error of the depth estimation from the proposed approach.

(a) First image

(b) Second image

Figure-7. Set of images from the hardware setup.

Table-2. Depth value for five points at the starfruit (in cm).

Point	Actual Value	Calculated Value	Relative Error
1	3.11	3.10	0.003
2	4.12	4.14	0.005
3	5.07	5.07	0.000
4	6.22	6.23	0.001

From the result of the Table-2, the relative error is less than 1% when using the startfuit image as benchmark. This is because the relative size of starfruit is much larger compare to the boxes used.

CONCLUSIONS

A single camera stereo vision system for moving starfruit on conveyor has been introduced. The 1 mm accuracy of depth resolution provided from the proposed system can be implemented for others close range inspection application. The low accuracy of the baseline on moving starfruit was one of the system's limitations which will decrease the depth resolution. But compared to the large size of starfruit, the accuracy of 1mm can be overlook. The future work will be focus on solving the baseline accuracy problem using automatically measurement through video input.

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