Biblid: 1821-4487 (2011) 15; 3; p.194-196
UDK: 004.352:631.151.4

Original Scientific Paper
Originalni naučni rad

3-D SCANNING SUBSYSTEM FOR VISUAL INSPECTION OF AGRICULTURAL PRODUCTS
3-D SKENERSKI PODSISTEM ZA VIZUALNU INSPEKCIJU POLJOPRIVREDNIH PROIZVODA

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ABSTRACT

The subject of this paper is the system scanning and 3-D model determination. The main purpose of the proposed system is a 3-D model reconstruction of agricultural products. The purpose of these models is the determination of examined product dimensions and calculation of other relevant parameters such as volume or shape. In addition to physical characteristics, the system allows the analysis of the product colors which are one of the most important parameters. The paper describes details of the pinhole camera model that is used during calibration and scanning, which allows the removal of image distortions resulting from the imperfection of optics (lens distortion). Calibration procedures are presented with one camera as well as with stereo cameras. It is possible to determine the point in real space and to create a model of the observed object by using stereo triangulation and camera model parameters. Finally, we show the results of the system operation as well as possible improvements which can increase performance.
Key words: *3D scanning, epipolar geometry, stereo visual systems, agricultural products.*

REZIME

Tema ovog rada je sistem za skeniranje i određivanje 3-D modela. Sistem je predviđen za dobijanje 3-D modela poljoprivrednih proizvoda. Na osnovu dobijenih modela moguće je odrediti dimenzije posmatranog proizvoda, i izračunati druge relevantne parametre kao što je zapremina ili oblik. Pored fizičkih karakteristika, sistem omogućuje utvrđivanje boje proizvoda koja je jedan od veoma bitnih parametara. U radu su opisani detalji pinhole modela kamere koji se koristi prilikom kalibracije i skeniranja, koji omogucuje uklanjanje deformacija slike nastalih kao posledica nesavršenosti optike (distorzija sočiva). Prikazani su postupci kalibracije jedne kamere kao i stereo kamera. Pomoću stereo trijangulacije i parametara modela kamera moguće je odrediti tačke u realnom prostoru i kreirati model posmatranog okruženja. Na kraju su prikazani rezultati rada sistema, kao i moguća unapređenja u cilju povećanja performansi istog.
Ključne reči: *3D skeniranje, Epipolarna geometrija, stereo vizualni sistemi, poljoprivredni proizvodi.*

INTRODUCTION

Agricultural products have many characteristics by which we can determine their quality and classify them. A large number of agricultural products entail a large number of parameters and important characteristics which can be observed. Some of the most important parameters are the size and color of a product (Babic and Babic 2009). The abovementioned parameters are common to all products and are the most important features used to determine the quality and therefore make classification. This paper describes a part of the system that allows visual inspection of the size and color of agricultural products. The system consists of a stereo camera, line-laser and software system for personal computer. Calibration procedures are presented with one as well as with two cameras (stereo cameras). The line-laser in the system is used as a marker to recognize the corresponding points in images obtained by using cameras. The result of scanning and program execution is a 3-D model that can be used to obtain the relevant product parameters (length, width, thickness) and the calculation of other parameters (volume). Besides the aforementioned, the system allows storing information about product color.

MATERIAL AND METHOD

The 3D scanning system consists of two cameras and a line-laser that is used as a marker on the object during scanning process. The most important details of the algorithm for the 3-D scanning and modeling are: camera modeling, camera calibration and stereo camera 3-D scanning.

Camera Modeling

Camera model is based on pinhole camera geometry shown on Fig. 1. ***X*** represents coordinate in the space, while ***x*** is the point in the image plane. Transformation from space to image plane can be represented by Equation

$$(x, y, z)^T = (f\frac{X}{Z}, f\frac{Y}{Z}, f)^T \tag{1}$$

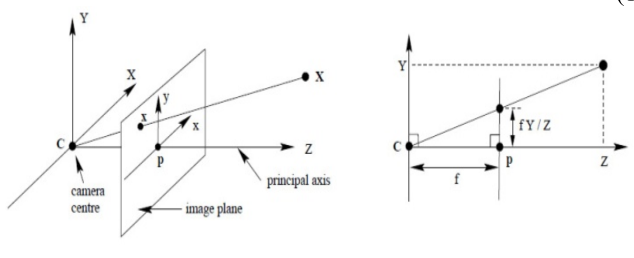

Fig. 1. Pinhole camera geometry
*(**C** is the camera center, **p** is the principal point)*

Homogenous coordinates

If the space and image points are represented by homogenous vectors, then mapping can be expressed in very simple way. The equation (1) may be written in terms of matrix multiplication as:

$$\begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \mapsto \begin{pmatrix} fX \\ fY \\ Z \end{pmatrix} = \begin{bmatrix} f & & & 0 \\ & f & & 0 \\ & & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{2}$$

$$x = PX \tag{3}$$

where P is homogeneous camera projection matrix. This matrix can be represented as:

$$P=\mathrm{diag}(f,f,1)[I|0]. \tag{4}$$

Principal point offset

Principal point offset is defined as difference between two coordinate systems. The first one is positioned in the camera focus, and the other one in the center of the image. The expression (1) assumed that the origin of coordinates in the image plane is at the principal point. In practice, it may not be the case (Fig. 1), so the general mapping should be used:

$$(X,Y,Z)^T \rightarrow \left(\frac{fX}{Z} + p_x, \frac{fY}{Z} + p_y\right)^T \tag{5}$$

$$\begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \rightarrow \begin{pmatrix} fX + Zp_x \\ fY + Zp_y \\ Z \end{pmatrix} = \begin{bmatrix} f & & p_x & 0 \\ & f & p_y & 0 \\ & & 1 & 0 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} \tag{6}$$

Now we define:

$$K = \begin{bmatrix} f & & p_x & 0 \\ & f & p_y & 0 \\ & & 1 & 0 \end{bmatrix} \tag{7}$$

The matrix K is called the camera calibration matrix.

$$x = K[I|0]X_{cam} \tag{8}$$

Camera rotation and translation

In general, points in space will be expressed in terms of a different Euclidean coordinate frame, known as the *world coordinate frame*. The two coordinate frames are related via a camera rotation and translation matrix. If **X** is an vector representing the coordinates of a point in the *world coordinate frame*, and **X**cam represents the same point in the camera coordinate frame, then we may write:

$$X_{cam} = \begin{bmatrix} R & -R\tilde{C} \\ 0 & 1 \end{bmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} = \begin{bmatrix} R & -R\tilde{C} \\ 0 & 1 \end{bmatrix} X \tag{9}$$

where $\tilde{C}$ represents the coordinates of the camera centre in the *world coordinate frame*. Putting this together with (8) leads to the formula:

$$x = KR[I|-\tilde{C}]X \tag{10}$$

General pinhole camera projection matrix P=KR[I|-C], has 9 degrees of freedom. The parameters contained in $\boldsymbol{K}$ ($\boldsymbol{f}$, $\boldsymbol{p_x}$, $\boldsymbol{p_y}$) are called the internal camera parameters. The parameters of the rotation matrix $\boldsymbol{R}$ and coordinates of the camera $\tilde{C}$ which relate the camera orientation and position are called external parameters.

Camera calibration

Camera calibration in the context of three-dimensional machine vision is the process of determining the internal camera geometric and optical characteristics (intrinsic parameters) and/or the 3-D position and orientation of the camera frame relative to a certain world coordinate system (extrinsic parameters). In many cases, the overall performance of the machine vision system strongly depends on the accuracy of the camera calibration.

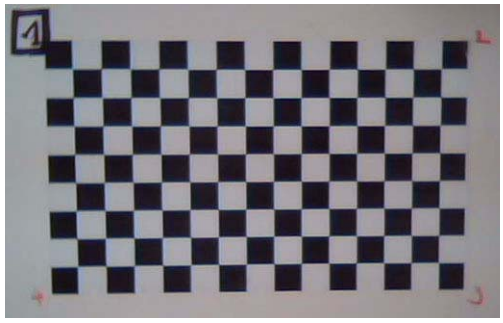

Fig. 2. Cash-board calibration pattern

In this paper we use camera calibration tool, written for the *Matlab* programming language that use chess-board pattern shown on the

Fig. 2. Complete calibration technique are described in the (*Zhengyou 1999*).

Calibration consists of three general steps:

- creating and loading calibration pattern images
- grid corner extraction and
- main calibration step

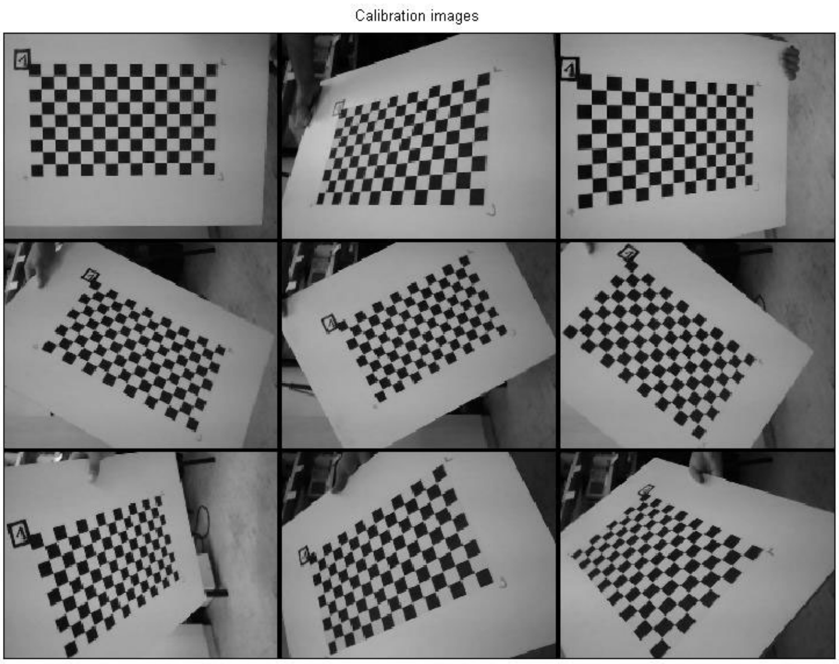

Fig. 3. Calibration pattern board in different position, loaded in tool box

The first step involves creating images where the calibration pattern is placed in different positions relative to the camera. Fig. 3 shows 9 images where patterns are in different positions. After loading the images into the program it is necessary to extract the corners. The extraction involves labeling the four extreme corners of the template on all images for calibration, and automatically extraction of all the others. Finally, the last step is the main calibration (initialization and nonlinear optimization), which creates internal and external parameters of the camera for further use.

Stereo camera 3-D scanning

The 3-D scanning system consists of two cameras with stereo calibration. Stereo calibration is a process that consists of calibration of each camera individually, after which the internal and external camera parameters are used for their mutual (stereo) calibration. Determining the position of one camera over another, i.e. determining the rotation matrix (***R***) and translation matrix (***T***) of the first camera over another is task of the stereo calibration (*Hartley and Zisserman, 2003*). Upon completion of this process, stereo system is ready for 3-D scanning. The process of 3-D modeling is based on stereo triangulation. If we look at a single point in space, to determine its coordinates, it is necessary to transmit the coordinates of this point in the coordinate system of the first and second camera to triangulation module. Details about stereo triangulation are shown in the (*Ho Li and Kleeman 2006*).

RESULTS AND DISCUSSION

Using the described system, two objects are scanned. The first object is a ball with a diameter of 60 mm. The second object is a box with dimensions: length 130 mm, width: 45 mm, thickness: 90 mm. The objects are placed so that the distance between them is 55 mm (fig.4).

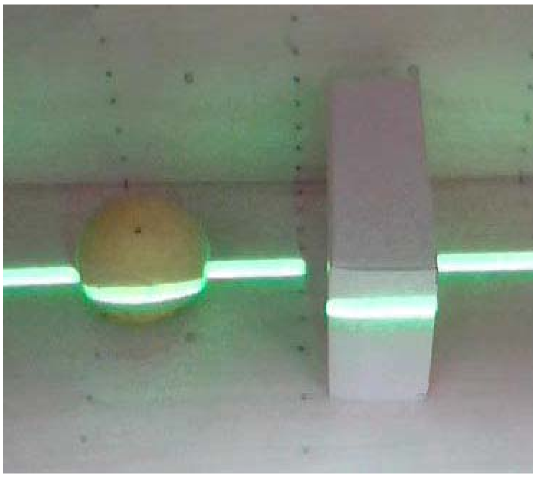

Fig. 4. Test environment with known object dimensions and green laser line. This is an image from the left stereo camera

Table 1. Real scene dimensions and dimensions measured with 3-D modeling software

[mm]	Ball	Cube			Distance
	Radius	Length	Width	Thickness	
Real dimensions	60.0	130.0	45.0	90.0	55.0
3-D model dimensions	58.2	130.2	45.0	90.1	55.0
Error	-1.8	0.2	0.0	0.1	0.0

In fig 5, a 3-D model of the scene obtained after scan is shown. Table 1 shows the real object dimensions and dimensions measured with 3-D modeling software.

Based on the results, we found that the maximum absolute error is 1.8 mm (corresponds to a value of 3%).

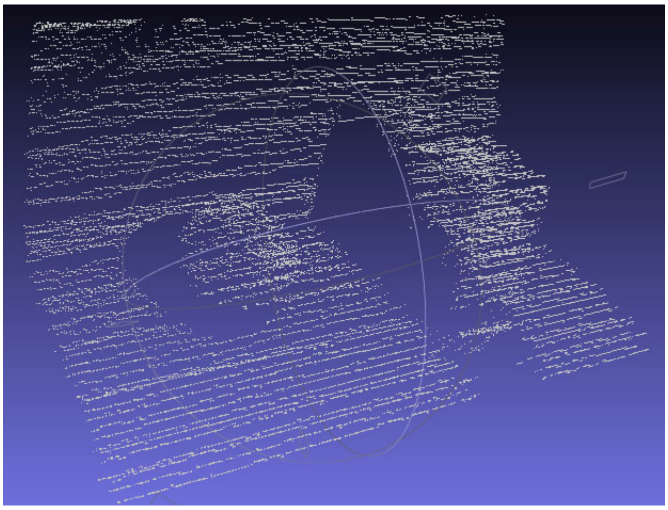

Fig. 5. Reconstructed 3D model of test environment

CONCLUSION

In this paper we describe a 3D stereo vision subsystem which consists of two cameras and a line-laser as a part of visual inspection and classification system for agricultural products. Scanning objects by using such a system can result in shortage of object point, but this defect can be resolved by using stereo system with more than two cameras. One of the limitations of this system, in obtaining the model, is the need to overwrite the object with line-laser. If the system requires more quickly obtaining models, it is possible to use the visual pattern projection on the object. This method allows obtaining 3-D models in only 2 or 3 frames, but requires a system for visual pattern projection and correction of certain parts of the program. In the future, the system can be improved with multi-camera environment to equip the 3-D model with more details (*Svoboda, 2005*), (*Svoboda et al., 2005*). Furthermore, using higher quality cameras can greatly improve performance and lead to a better agricultural product classification.

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Received: 15.11.2011. Accepted: 08.12.2011.