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DIGITAL CAMERA AND 3D LASER RANGE FINDER SYSTEM CALIBRATION FOR ROBOT NAVIGATION

Abstract

Navigation of autonomous mobile robots in 3D needs information about environment their are operating. One of the ways to get that information is by the use of various 3D range finders. Currently, modern 3D laser scanners are very expensive, therefore in the paper we propose the new 3D range scanner composed of the 2D laser scanner with an extra gear supplying the third degree of freedom. Such combination allowed building a non-expensive 3D range scanner, suitable for mobile robots navigation in 3D. Scanning system effectiveness was evaluated between the known and measured object dimensions.

This paper describes the calibration of digital camera with 3D laser range finder system. Then the 2D image matrix elements can be attributed to the depth of the 3D laser scanner data. Such mapping might be also available in the reverse option to 3D laser scanned points assign the real colour of an object from the digital camera data array. 3D laser scanning system can provide spatial information about objects in the environment regardless of the texture. The synergy of these systems, we get not only the position of objects in environment, but also the texture. Composed of 2D image data array depth map can be used for identification of objects in the environment, avoiding obstacles etc.

Objectives. Create and calibrate 3D scanning system from digital camera and 2D laser range finder with an extra gear supply. From the synergy of these systems, get not only the position of objects in environment, but also the texture.

1. Experimental setup. In our work, we use 2D laser range finder UBG-04LX-F01 (Rapid-URG) [3] for area scanning and 3000 – Hitec- HS-422HD servomotor for supplying the third degree of freedom to the scanning system. The light source of the sensor is infrared laser of wavelength 785nm with laser class 1 safety.

The designed system has digital camera (type FFMV-03MTC-60, mfg. Point Grey, Canada), mounted in parallel with laser range finder UBG-04LX-F01. In our work we have applied Jean-Yves Bouguet's well known and widely used Camera Calibration Toolbox for MATLAB [6] to calibrate the digital camera parameters and to compensate nonlinear radial and tangential distortion of the pinhole camera. Camera calibration was made only to rectify the images and to find the camera model based parameters. The equation of the pinhole camera model is [1, 2]:

$$\begin{bmatrix} u \\ v \\ 0 \end{bmatrix} = \frac{f}{z_c} \cdot \begin{bmatrix} k_u & 0 & \frac{u_0}{f} \\ 0 & k_v & \frac{v_0}{f} \\ 0 & 0 & \frac{1}{f} \end{bmatrix} \cdot \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} \tag{1}$$

where u, v – are the retinal coordinates, x_c, y_c, z_c – the world coordinates, k_u, k_v – the scale factors along the axes of pixel coordinates, u_0, v_0 – the pixel coordinates of the principal point (orthogonal projection of the optical center on the image plane), f – the focal length.

Laser range finder data are expressed in spherical coordinates. The sensor model can be written as [4]:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} c_i c_j & -c_i c s_j & s_i & c_i d_x + s_i d_z \\ s_j c_i & c_i & 0 & 0 \\ s_i & s_i c s_j & c_i & s_i d_x + c_i d_z \end{bmatrix} \begin{bmatrix} \rho_{ij} \\ 0 \\ 0 \\ 1 \end{bmatrix} \tag{2}$$

where $c_i = \cos(\varphi_i)$, $c_j = \cos(\theta_j)$, $s_i = \sin(\varphi_i)$, $s_j = \sin(\theta_j)$, ρ_{ij} is the j-th measured distance with corresponding orientation θ_j in the i-th scan plane, which makes the angle φ_i with the horizontal plane. The offset of the external rotation axis from the centre of the mirror in the laser frame has components $d_x = 90\,mm$ and $d_z = 20\,mm$. $[x, y, z]^T$ is the coordinates of each measured point relative to the global frame (with its origin at the centre of the rotation axis, the x-axis pointing forward and the z-axis toward the top).

After multiplication with the laser scanner data (ρ_{ij}) (2), the following structure results, this can be simply implemented and takes up only little computing time:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} c_i c_j \rho_{ij} + c_i d_x + s_i d_z \\ c_i s_j \rho_{ij} \\ s_i \rho_{ij} + s_i d_x + c_i d_z \end{bmatrix} \tag{3}$$

2. Results. 3D scanned calibration area view in Matlab:

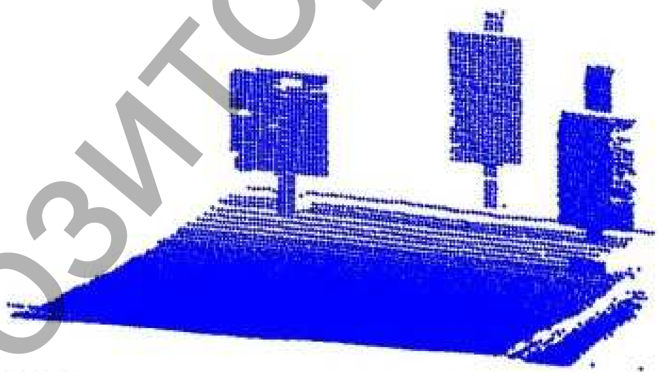

Fig. 1 – 3D scanned calibration area view in Matlab

Base on (1) and (3) using least squares (lsq) and 24 calibration points we fit the model function:

$$f(x) = cx(3) + \frac{cx(2) \cdot \left(x_c + cx(1)\right)}{z_c - cx(4)} \tag{4}$$

$$f(y) = cy(3) + \frac{cy(2) \cdot \left(y_c + cy(1)\right)}{z_c - cy(4)} \tag{5}$$

With coefficients *cx* and *cy*: *cx* = [111.2 479.1 254.7 39.0]; *cy* = [175.8 550.4 235.3 19.8].

Calibrated 24 points (corners of boxes) from 3D point could (Fig. 1) and undistorted image we can see in Fig. 2.

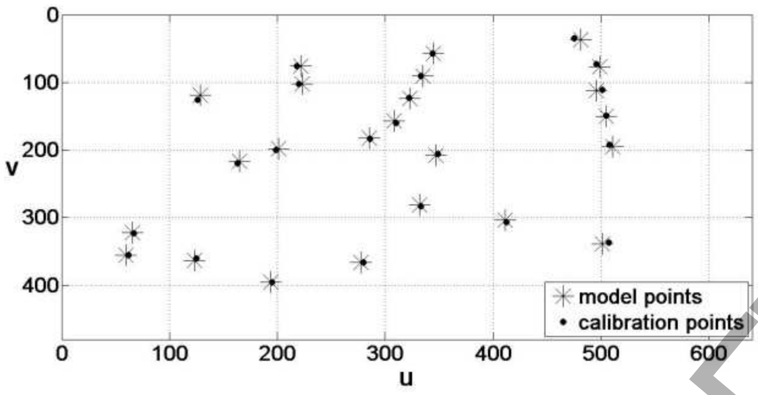

Fig. 2 – Calibration results

In Fig. 2 and Fig. 3 we can see how good model points (Asterisk) correspond to calibration points (dots)

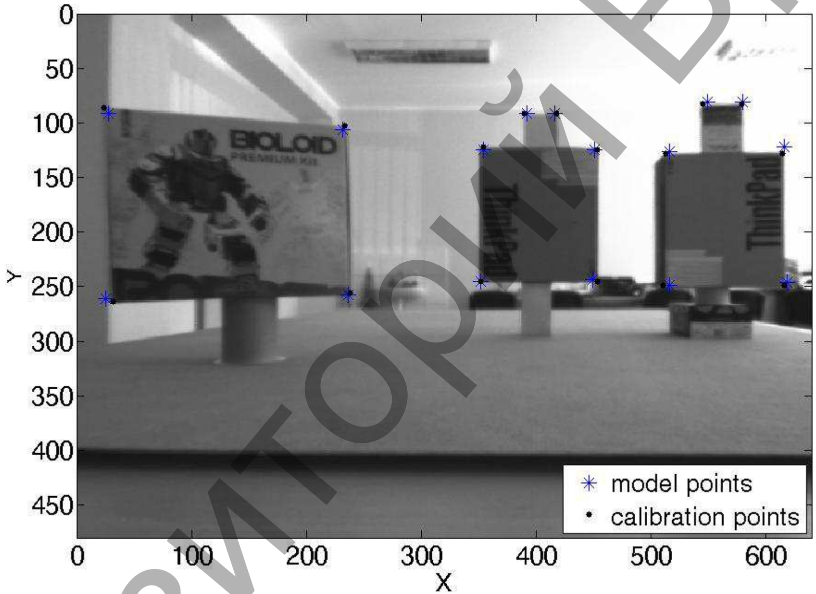

Fig. 3 – Calibration results on (one from two) picture

After carried out calibration, we get the scanned scene Fig. 4.

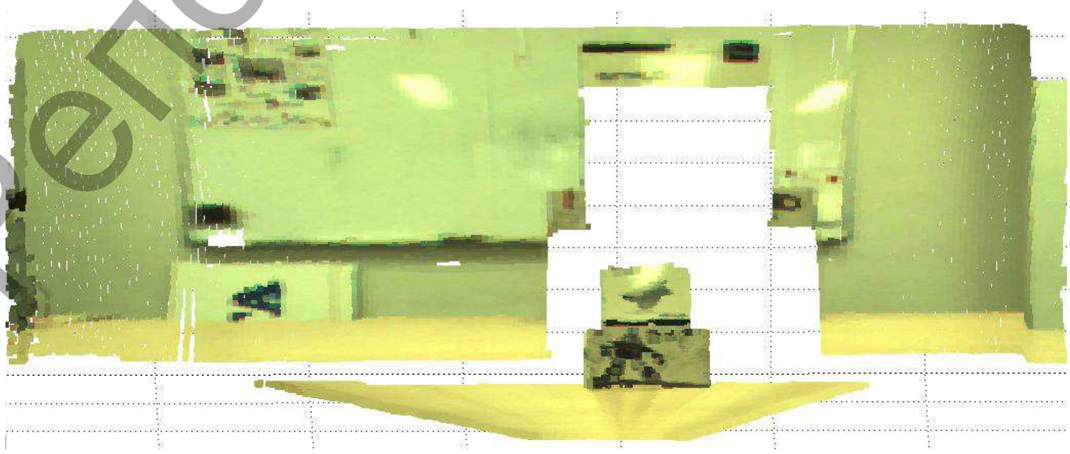

Fig. 4 – Scene after calibration

Algorithm for CCD camera integration with 3D laser scanner is shown in Fig. 5.

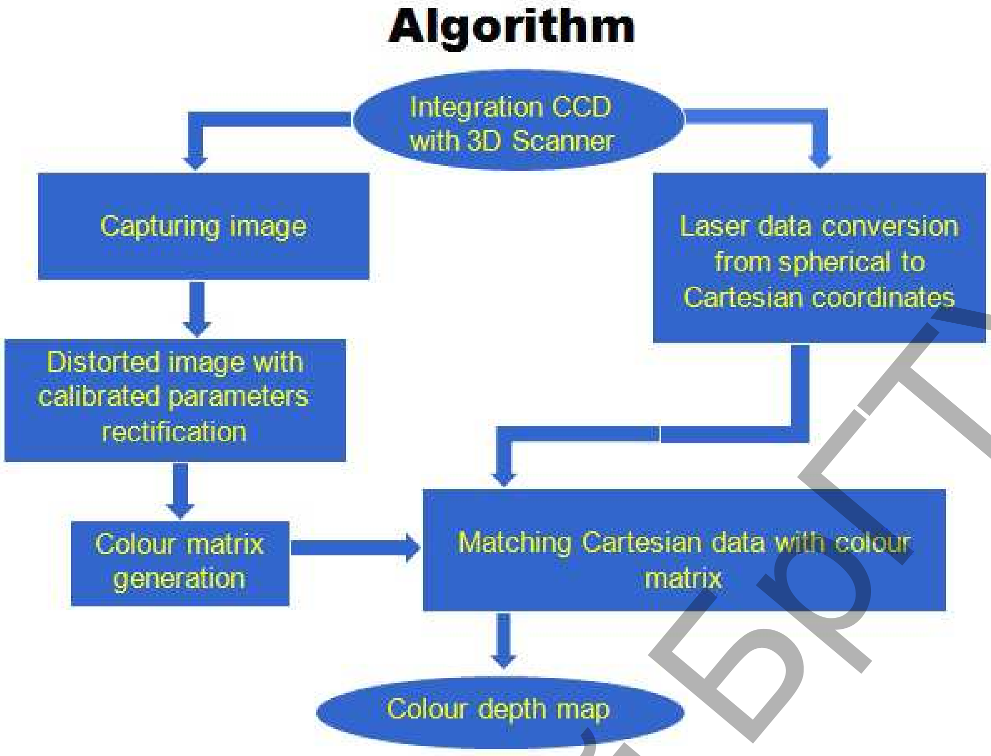

Fig. 5 – Algorithm for CCD camera integration with 3D laser scanner

Conclusions. We created the system which makes the colour depth map using CCD camera integration with 3D Laser range scanner. Calibration point's Euclidian distance absolute mean error was 4.7 pixels. This system can be used for robot navigation, 3D SLAM, object recognition or other tasks.

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