Extrinsic Calibration of a Camera and a Laser Range Finder using Point to Line Constraint

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Abstract

In this paper, a novel extrinsic calibration method of a camera and a laser range finder is presented using a calibration cube. The calibration is based on observing three edges of the cube from the camera and three laser points projected onto the edges from the laser finder. The equation for extrinsic calibration parameters, a rotation matrix and a translation vector, is built based on the constraint that in the image coordinate the projection of laser point onto the image plane is on that of the three cube edges. The parameters are calculated with three changes of pose of the cube. Experimental result shows that the proposed method is feasible and accurate.

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Keyword: Camera; Extrinsic calibration; Laser range finder

1. Introduction

Accurate measurement of the 3-D shape of objects is an important and rapidly expanding study topic in the fields of computer vision. Applications include entertainment, computer graphics, computer aided design and digital simulation [1,2]. For the camera and laser range finder exist in different coordinate system, it is required to determinate the relative position and orientation, i.e., the extrinsic calibration between them to get the geometry interpretation of the measurement.

Many algorithms have been proposed for the extrinsic calibration between 2D laser range finder and perspective camera [3-5]. Some of this works use the visible position of the laser point [3], while others use the invisible laser point to the camera [4]. Zhang and Pless [4] utilized a chess calibration board and

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solved the extrinsic calibration using the constraints between the parameter vector of the calibration board and the distance from the camera to board. Mei and Rives [5] developed a more general theory of extrinsic calibration and considered the calibration between a laser range finder and a central catadioptric camera including the perspective one [4]. The methods devised for the extrinsic calibration between camera and 2D laser range finder has also been extended into 3D cases.

In this paper, we propose a simple method for calibration of a camera and a laser range finder. This method employs a cube as a calibration reference imaged simultaneously by the camera and laser range finder. For each different pose of the cube, the equation for extrinsic calibration parameters between the camera and laser range finder is built based on the constraints that in the image coordinate the projection of laser point projected onto the cube edge sits on the image of the three cube edges. Thus, for the point to line constraint used, a linear equation for unknown variable is obtained which is easily to be solved.

Fig. 1. The configuration for calibration between a camera and a laser range finder. The calibration cube are both imaged with the camera (Block A) and the laser range finder (Block B).

2. Method

Fig. 1 shows the illustration of the proposed calibration method in this paper. The surface of the calibration cube employed in this paper is chessboard squares with area of 50 cm × 50 cm. The laser range finder scans the cube to produce the distance information of two dimensional plane contours and the camera captures the image information of the cube, where the three edges $L_1, L_2$ and $L_3$ can be simultaneously captured by the laser range finder and camera.

2.1. Imaging of cube edges in camera

The imaging model of a camera can be described with a pinhole model. The relationship between a point and its projection on the image plane can be described as $sI = KP_c = K[M,N]P_w$, where $I$ is the homogeneous coordinate of the image point in the image coordinate system, $P_w = [x_w, y_w, z_w, 1]^T$ is the homogeneous coordinate of the point in the world coordinate system. $P_c = [x_c, y_c, z_c]^T$ is camera coordinate of the point in the camera coordinate system. $s$ is a scale factor. $K$ is the inner parameter matrix.

The inner parameters are known in the following process when the camera is calibrated. The calibration method proposed by Zhang [6] is adopted to calibrate the inner parameter of the camera. Lastly, we build the line equation of the projection from cube edge to image plane. The Harris detector is used to detect the corner point. With the coordinate of the detected corner, the line equation is fitted with least square method. The line equation can be expressed as

$$Au + Bv = 1$$  \hspace{1cm} (1)
where $A, B$ are the reciprocal of the intercept of axis $U$ and $V$ intersected by the line, respectively.

2.2. Laser range finder imaging

The laser ranger finder produces 2D range scans consisting of discrete angular samples on a plane parallel to the floor. For each ray sample along the direction of angle $\theta_k$, a corresponding distance $r_k$ along the ray can be obtained. A laser coordinate system is defined with the origin at the laser ranger finder, and the laser scan plane is the plane $Z_l = 0$; the ray $\theta = 0$ is coincident with the $X_l$ axis of laser coordinate system and the ray $\theta = \pi/2$ is coincident with the $Y_l$ axis. Therefore, the scan provides measurements of the form

$$P_l^k = r_k [\cos \theta_k, \sin \theta_k, 0]^T$$ (2)

where $P_l(x_l, y_l, z_l)$ is the coordinate of laser point in laser coordinate system.

Since the scan scope of the laser is $180^\circ$ in the plane $z_l = 0$ and the laser point on the calibration cube belongs to part of all the laser points, it is required to detect the point cloud on the calibration cube. The detection method is as follows; firstly, the empty scene without a calibration cube is scanned to obtain the distance information set $d$. Then the scene with the cube is scanned to obtain the distance information set $D$. The angle distance between $d$ and $D$ will be changed greatly after placing the calibration cube. The point cloud can be detected by setting a threshold for the difference between $d$ and $D$.

2.3. System calibration

Suppose a point $P_c$ in the camera coordinate system is located at a point $P_l$ in the laser coordinate system, and the rigid transformation from the camera coordinate system to laser coordinate system can be described by:

$$P_l = RP_c + T$$ (3)

Since all the laser points are on the plane $z_l = 0$ in the laser coordinate system, the above equation can be formulated as

$$x_c = r_x x_l + r_y y_l + t_z; y_c = r_x y_l + r_y y_l + t_x; z_c = r_x x_l + r_y y_l + t_z$$ (4)

The image coordinate of $P_c$ projected onto the image plane can be derived as:

$$u = f_x x_c / z_c + u_0; v = f_y y_c / z_c + v_0$$ (5)

With Eqs. (4) and (5), the image coordinate of the laser point projected onto the image plane can be denoted with its laser coordinate by replacing $x_c, y_c$ and $z_c$ in Eq. (5) with the right of Eq. (4).

Since the image coordinate of the laser point in the image plane must lie on the line corresponding to the view of the three cube edges from the camera, we get a geometry constraint on the rigid transform between the camera coordinate system and laser coordinate system. Putting the image coordinate obtained above into the line equation in Eq. (1) produces the below equation for the rigid transform $R$ and $T$:

$$A f_x (r_x x_l + r_y y_l + t_z)/(r_x x_l + r_y y_l + t_x) + B f_y (r_x y_l + r_y y_l + t_y)/(r_x x_l + r_y y_l + t_z) + B v_0 = 1$$ (6)

It can be can be further transformed into

$$cx = -p$$ (7)
where $p = A u_0 + B v_0 - 1$.

For each calibration point, an equation like Eq. (7) can be obtained after the determination of the coordinate of a point in the laser coordinate system and the corresponding linear equation in image coordinate. For each pose of calibration cube three edges can be simultaneously captured by the camera and laser ranger finder. Thus, nine laser points and the corresponding line equations of the edges can be obtained provided that the calibration cube changes its position three times. An overdetermined linear equation group can be built and solved by the least square method.

The values of $r_1/t_z$, $r_2/t_z$, $r_3/t_z$, $r_4/t_z$, $r_5/t_z$, $r_6/t_z$, $r_7/t_z$, $r_8/t_z$, $r_9/t_z$ are firstly obtained by solving the equations, and then the value of $t_z$ can be derived according to the orthogonal property of $R$.

3. Experimental result and analysis

3.1. Experimental result

For each pose of calibration cube, the image of the cube can be obtained with the camera imaging. The corner detection algorithm is applied to the image and line fitting method is used to get the three line equation according to the three edges of cube. For the influence of different noise, some errors will happen to the object distance data collected by the laser range finder. This is reflected in the two dimensional contour image. The two surfaces of cube facing the laser ranger finder cube are all planes. Thus, the laser points should lie in one polygonal line consisting of two line sections. However, the real result of the measured laser points fluctuates near the real value. This causes the computation of the image coordinate of the laser points projected onto the image plane, and affects the computation accuracy of estimation for $R$ and $T$.

We can decrease the estimation error through fitting the laser measurement with a polygonal line consisting of two line sections. The three extreme points of the polygonal line are taken as the distance records corresponding to the three laser points projected onto the three edges of cube.

With the obtained data of no less than 8 groups of the calibration points and linear equations, the least square method is utilized to compute the equation group composed by Eq. (7), which can be simplified into matrix form of $CX = Y$. The last computation results of $R$ and $T$ are obtained.

3.2. Validation and precision analysis

According to the computation results of $R$ and $T$, the laser data can be potted on the image to show the performance of the estimation result. The angle frequency of the laser is 0.5° here and two instances, a plane object and a curved surface object are used. Fig. 2 demonstrates the results of the algorithm applied to the instances. The laser points are mapped onto the object with estimated $R$ and $T$. Though the ground truth of the extrinsic parameters $R$ and $T$ are not known, the mapping results are reasonable for the mapped laser points lie in a plane parallel to the ground by visual inspection.

4. Conclusions

This paper presents a novel extrinsic calibration method for a camera and a laser range finder. Spatial average is used to decrease the observation error through making using of the inner structure within calibration target. Therefore, lessen calibration points are needed for the calibration. Only the requirement of varying the location of the calibration cube three times, the method can solve the rotation matrix and transition vector. For the point to line constraint are used, linear equation for the unknown variables is obtained, which is easily solved. Experiments have shown that the proposed method is feasible and
Fig. 2. Validation result of instance where the laser range finder points are projected on the image using the computed $R$ and $T$. (a) The plane object; (b) The curved surface object

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