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Study on Optimum Line Configuration for Location Model in Computer Vision

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Abstract: The characteristics for propagation of quantization errors for the question of pose estimation from line correspondences are introduced in this paper because quantization errors are the primary factors that affect the accuracy of pose estimation. Mathematical model of the propagation of quantization errors from images of line features to results of pose estimation could be set up in the form of closed-form solution. The research has some theoretical value. Furthermore, it has some practical value. One of important applications is to find the optimum line configuration. In priority, the paper presents the method to find the optimum line configuration based on quadrangular frustum pyramid model and determine the optimum line configurations on the analysis of the quantization errors. This analysis can increase the accuracy of pose estimation in computer vision.

Keywords: Optimum line configuration, Quadrangular frustum pyramid, Location model, Quantization errors, Computer vision

1 Introduction

In the nineteen seventies, researchers of Marr, Barrow and Tenenbaum are as the representative people to put forward a complete set of visual computing theory for describing vision process. In visual research theory, Marr theory is far-reaching and it becomes the dominant idea in this field. Three-dimensional shape recovery from image objects is its core. Computer vision has made a large number of results in the Maldives framework after nearly thirty years of development.

Pose measurement is to measure the position and orientation of object by means of certain technical methods in the reference coordinate system. Pose measurement has important application value in some fields. It has been used in mechanical processing, the m obile robot, space technology, ship, satellite and other fields widely [1, 2]. It mainly includes target acquisition and pose estimation to complete a visual measurement process. In computer vision, model-based monocular pose estimation is an important problem.

Currently, the pose measurement methods include methods of line-based pose estimation and methods of point-based pose estimation. In practical application, accuracy of line detection is often higher than point feature because the images of measurement object we obtain are often unclear and occluded. Thus, pose measurement from line features [3, 4] are usually more robust than that of point features.

Quantization errors [5–7] are the primary source to affect the pose estimation accuracy. Previous researchers have proposed some results of the quantization errors in the model-based pose measurement system. Wong [8] used statistic characteristic function for describing the three-dimensional error. L. Tiecheng [9] presents a stochastic error diffusion approach and analyzes its effect on image quality and artifacts. Matthies Shafer [10] estimated the errors in navigation of mobile robot. Ii is assumed that error is in the distribution of Gaussian form. They describe error in using of matrix form, because it is easy for computing. McBey [11] introduces situation of quantization errors in computer system. Kamgar-Parsi [12] developed mathematical tools for computing average error of quantization. Blostein [13] analyzed the error effect of image plane quantization on the three-dimensional point position by triangulation in stereo setup. Rodriguez [14] did stochastic analysis for three-dimensional point quantization error in stereo vision. Griffin [15] discussed a method to integrate errors in the process of visual inspection process. Ho [16]

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expressed the digitizing error for various geometric features on measurement object. At present, most research focuses on error analysis for point features, there is little research which is proposed for error analysis from line features.

Paper [17] analyzes the error in two measured dimensions of a line. Mean, variance and range of the error are derived. In the pose estimation process, quantization errors are not constant and it depends on the computation value. The effect of the quantization errors on the precision of dimensional measurements of lines is introduced in the paper. Research of how these quantization errors propagate from two-dimensional (2D) image plane to three-dimensional (3D) model is little. Paper [18] introduces the research on quantization error for pose estimation from line correspondences and how the quantization errors affect the accuracy of pose estimation.

Analysis on the effect of quantization errors from image lines at pose estimation results with line correspondences can be used to direct the design of the intrinsic parameters of system and optimize the characteristic of system in project. Furthermore, one of important applications is to estimate the error range of pose estimation system and direct optimum line configuration of location model.

For one given model, quantization errors have different effects on line configurations of location model in model-based monocular pose estimation system. Thus, for different line configurations of location model, the accuracy of pose estimation is different. Thus, the analysis of different line configurations for location model is an important aspect to execute the vision task at high precision. At present, there is little research on the optimum line configurations of location model with respect to the camera according to the literatures we have referred. On the basis of introduction of the propagation of the quantization errors, we do deep research on the optimum line configurations of the quadrangular frustum pyramid model with respect to camera. The purpose of the research is to increase the accuracy of pose estimation.

Remainder of this paper is organized as follows: In section II, pose measurement method with line feature correspondences is introduced. Section III introduces the characteristic of propagation for quantization errors in computer vision. In section IV, the method to determine the optimum line configurations for quadrangular frustum pyramid pose measurement model is presented in priority. In section V, experimental results are proposed. The conclusion is presented in Section VI.

2 Pose measurement from line features in computer vision

See Fig.1, the parameters of the projection (the intrinsic camera parameters) are known and a pin-hole camera

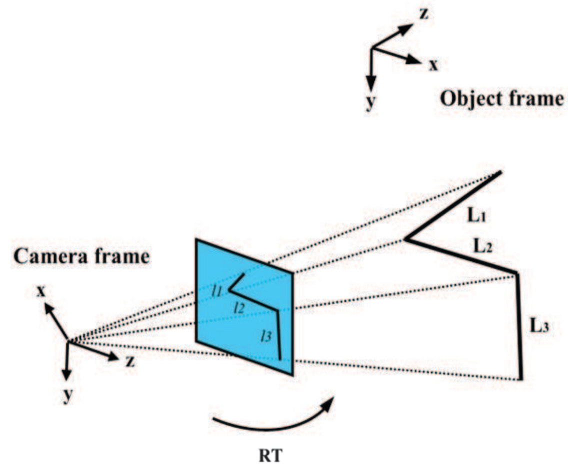

Figure 1: Pose measurement from straight line features

model is assumed. The vectors of model line L_i $(i = 1,2,3)$ is assumed. The perspective projection model constraints model line, image line and the origin of the camera frame to lie in the same plane. This plane is called explanation plane. The vector normal to this plane is $N_i = (a_i f, b_i f, c_i)$.

Vectors of space line L_i in the object frame are assumed as $\mathbf{n}_i = (A_{wi}, B_{wi}, C_{wi})$. Rotation matrix between the camera frame and the object frame is R. Space line in the camera frame after the rotation is V_i, then we get:

$$V_i = R\mathbf{n}_i \tag{1}$$

$$R = \begin{pmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{pmatrix} \tag{2}$$

where:

$R_{11} = \cos\gamma\cos\beta; R_{12} = \cos\gamma\sin\beta\sin\alpha - \sin\gamma\cos\alpha;$
$R_{13} = \cos\gamma\sin\beta\cos\alpha + \sin\gamma\sin\alpha;$
$R_{21} = \sin\gamma\cos\beta; R_{22} = \sin\gamma\sin\beta\sin\alpha - \cos\gamma\cos\alpha;$
$R_{23} = \sin\gamma\sin\beta\cos\alpha - \cos\gamma\sin\alpha; R_{31} = -\sin\beta;$
$R_{32} = \cos\beta\sin\alpha; R_{33} = \cos\beta\cos\alpha.$

The normal of explanation plane is perpendicular to the space line, then we can get equation about rotation matrix R as follows [8]:

$$\mathbf{N}_i \cdot R\mathbf{n}_i = 0 \tag{3}$$

Rotation parameters of the rotation matrix R are obtained from three image lines. The solution condition is there are not two lines which are parallel, and lines do not pass the optical centre.

3 Characteristics for propagation of quantization for line features in computer vision

Errors of image lines will lead to errors of rotation angles α,β,γ because of quantization errors. In this section, we will introduce the relationship between quantization errors and errors from rotation angle α,β,γ. Error of norm vector $N_i=(N_{i1},N_{i2},N_{i3})$ in the explanation plane is assumed to be dN_i in the reason of quantization errors. From the effect of quantization errors, errors of the pose measurement result is assumed to be $dR=(d\alpha,d\beta,d\gamma)$. In vision pose estimation method from three line correspondences, we obtain expression (2) and the following:

$$\mathbf{n}_1=\begin{pmatrix}A_{wi}\\B_{wi}\\C_{wi}\end{pmatrix}\quad \mathbf{N}_i=\begin{pmatrix}N_{i1}\\N_{i2}\\N_{i3}\end{pmatrix} \tag{4}$$

Formula (4) is substituted into (3), equations between α,β,γ and (N_{11},N_{12},N_{13}), (N_{21},N_{22},N_{23}), (N_{31},N_{32},N_{33}) is get:

$$\begin{cases}F_1(N_{11},N_{12},N_{13},\alpha,\beta,\gamma)=0\\F_2(N_{21},N_{22},N_{23},\alpha,\beta,\gamma)=0\\F_3(N_{31},N_{32},N_{33},\alpha,\beta,\gamma)=0\end{cases} \tag{5}$$

In formula (5), $N\equiv[N_{11},N_{12},N_{13},N_{21},N_{22},N_{23},N_{31},N_{32},N_{33}]$, $R\equiv[\alpha,\beta,\gamma]$, $F\equiv[F_1,F_2,F_3]$, we do partial differential computation for equation set (5), the following is obtained:

$$\frac{\partial F}{\partial N}dN+\frac{\partial F}{\partial R}dR=0 \tag{6}$$

Therefore, error dN of N and error dR of R have the relationship as below:

$$dR=-\left(\frac{\partial F}{\partial R}\right)^{-1}\left(\frac{\partial F}{\partial N}\right)dN \tag{7}$$

Formula (7) can be reorganize into expression (8):

$$\begin{cases}m_{11}d\alpha+m_{12}d\beta+m_{13}d\gamma+m_{14}dN_{11}\\m_{21}d\alpha+m_{22}d\beta+m_{23}d\gamma+m_{24}dN_{21}\\m_{31}d\alpha+m_{32}d\beta+m_{33}d\gamma+m_{34}dN_{21}\end{cases}$$
$$\begin{matrix}+m_{15}dN_{12}+m_{16}dN_{13}=0\\+m_{25}dN_{22}+m_{26}dN_{23}=0\\+m_{35}dN_{22}+m_{36}dN_{23}=0\end{matrix} \tag{8}$$

In equation (8):

$$m_{11}=N_{11}((cos\gamma sin\beta cos\alpha+sin\gamma sin\alpha)B_{w1}+(-cos\gamma\, sin\beta sin\alpha+sin\gamma cos\alpha)C_{w1})+N_{12}((sin\gamma sin\beta\, cos\alpha-cos\gamma sin\alpha)B_{w1}+(-sin\gamma sin\beta sin\alpha-cos\gamma\, cos\alpha)C_{w1})+N_{13}(-cos\beta cos\alpha B_{w1}+cos\beta cos\alpha C_{w1})$$

$$m_{12}=N_{11}(-cos\gamma sin\beta A_{w1}+(cos\gamma cos\beta sin\alpha)B_{w1}+(cos\gamma cos\beta cos\alpha)C_{w1})+N_{12}(-sin\gamma sin\beta A_{w1}+(sin\gamma cos\beta sin\alpha)B_{w1}+(sin\gamma cos\beta cos\alpha)C_{w1})+N_{13}(-cos\beta A_{w1}-sin\beta sin\alpha B_{w1}-sin\beta sin\alpha C_{w1})$$

$$m_{13}=N_{11}(-sin\gamma cos\beta A_{w1}+(-sin\gamma sin\beta sin\alpha-cos\gamma\, cos\alpha)B_{w1}+(-sin\gamma sin\beta cos\alpha+cos\gamma sin\alpha)C_{w1})+N_{12}(cos\gamma cos\beta A_{w1}+(cos\gamma sin\beta sin\alpha-sin\gamma\, cos\alpha)B_{w1}+(cos\gamma sin\beta cos\alpha+sin\gamma sin\alpha)C_{w1})$$

$$m_{14}=cos\gamma cos\beta A_{w1}+(cos\gamma sin\beta sin\alpha-sin\gamma cos\alpha)B_{w1}+(cos\gamma sin\beta cos\alpha)+sin\gamma sin\alpha)C_{w1}$$

$$m_{15}=sin\gamma cos\beta A_{w1}+(sin\gamma sin\beta sin\alpha+cos\gamma cos\alpha)B_{w1}+(sin\gamma sin\beta cos\alpha-cos\gamma sin\alpha)C_{w1}$$

$$m_{16}=-sin\beta A_{w1}+cos\beta sin\alpha B_{w1}+cos\beta sin\alpha C_{w1}$$

$$m_{21}=N_{21}((-cos\gamma sin\beta cos\alpha+sin\gamma sin\alpha)B_{w2}+(-cos\gamma\, sin\beta sin\alpha+sin\gamma cos\alpha)C_{w2})+N_{22}((sin\gamma sin\beta cos\alpha-cos\gamma sin\alpha)B_{w2}+(-sin\gamma sin\beta sin\alpha-cos\gamma cos\alpha))\, C_{w2})+N_{23}(-cos\beta cos\alpha B_{w2}+cos\beta cos\alpha C_{w2})$$

$$m_{22}=N_{21}(-cos\gamma sin\beta A_{w2}+(cos\gamma cos\beta sin\alpha)B_{w1}+(cos\gamma cos\beta cos\alpha)C_{w2})+N_{22}(-sin\gamma sin\beta A_{w2}+(sin\gamma cos\beta sin\alpha)B_{w2}+(sin\gamma cos\beta cos\alpha)C_{w2})+N_{23}(-cos\beta A_{w2}-sin\beta sin\alpha B_{w2}-sin\beta sin\alpha C_{w2})$$

$$m_{23}=N_{21}(-sin\gamma cos\beta A_{w2}+(-sin\gamma sin\beta sin\alpha-cos\gamma\, cos\alpha)B_{w2}+(-sin\gamma sin\beta cos\alpha+cos\gamma sin\alpha)C_{w2})+N_{22}(cos\gamma cos\beta A_{w2}+(cos\gamma sin\beta sin\alpha-sin\gamma\, cos\alpha)B_{w2}+(cos\gamma sin\beta cos\alpha+sin\gamma sin\alpha)C_{w2})$$

$$m_{24}=cos\gamma cos\beta A_{w2}+(cos\gamma sin\beta sin\alpha-sin\gamma cos\alpha)B_{w2}+(cos\gamma sin\beta cos\alpha+sin\gamma sin\alpha)C_{w2}$$

$$m_{25}=sin\gamma cos\beta A_{w2}+(sin\gamma sin\beta sin\alpha+cos\gamma cos\alpha)B_{w2}+(sin\gamma sin\beta cos\alpha-cos\gamma sin\alpha)C_{w2}$$

$$m_{26}=-sin\beta A_{w2}+cos\beta sin\alpha B_{w2}+cos\beta sin\alpha C_{w2}$$

$$m_{31}=N_{31}((-cos\gamma sin\beta cos\alpha+sin\gamma sin\alpha)B_{w3}+(-cos\gamma\, sin\beta sin\alpha+sin\gamma cos\alpha)C_{w3})+N_{32}((sin\gamma sin\beta cos\alpha-cos\gamma sin\alpha)B_{w3}+(-sin\gamma sin\beta sin\alpha-cos\gamma cos\alpha)\, C_{w3})+N_{33}(-cos\beta cos\alpha B_{w3}+cos\beta cos\alpha C_{w3})$$

$$m_{32} = N_{31}(-cos\gamma sin\beta A_{w3} + (cos\gamma cos\beta sin\alpha)B_{w3} + (cos\gamma cos\beta cos\alpha)C_{w3}) + N_{32}(-sin\gamma sin\beta A_{w3} + (sin\gamma cos\beta sin\alpha)B_{w3} + (sin\gamma cos\beta cos\alpha)C_{w3}) + N_{33}(-cos\beta A_{w3} - sin\beta sin\alpha B_{w3} - sin\beta sin\alpha C_{w3})$$

$$m_{33} = N_{31}(-sin\gamma cos\beta A_{w3} + (-sin\gamma sin\beta sin\alpha - cos\gamma cos\alpha B_{w3} + (-sin\gamma sin\beta cos\alpha + cos\gamma sin\alpha)C_{w3}) + N_{32}(cos\gamma cos\beta A_{w3} + (cos\gamma sin\beta sin\alpha - sin\gamma cos\alpha) B_{w3} + (cos\gamma sin\beta cos\alpha + sin\gamma sin\alpha C_{w3})$$

$$m_{34} = cos\gamma cos\beta A_{w3} + (cos\gamma sin\beta sin\alpha - sin\gamma cos\alpha)B_{w3} + (cos\gamma sin\beta cos\alpha + sin\gamma sin\alpha)C_{w3}$$

$$m_{35} = sin\gamma cos\beta A_{w3} + (sin\gamma sin\beta sin\alpha + cos\gamma cos\alpha)B_{w3} + (sin\gamma sin\beta cos\alpha - cos\gamma sin\alpha)C_{w3}$$

$$m_{36} = -sin\beta A_{w3} + cos\beta sin\alpha B_{w3} + cos\beta sin\alpha C_{w3}$$

Where coefficient m is function about $\cos\alpha$, $\cos\beta$, $\cos\gamma$ and (A_{wi}, B_{wi}, C_{wi}) $(i = 1, 2, 3)$.

We have the following formula from equation (8):

$$d\alpha = \frac{-(f_{12}d\beta + f_{13}d\gamma + f_{14}dN_{11} + f_{15}dN_{12} + f_{16}dN_{13})}{f_{11}} \tag{9}$$

$$d\beta = \frac{(m_{13}m_{21} - m_{23}m_{11})d\gamma + G_1}{-m_{12}m_{21} + m_{22}m_{11}} \tag{10}$$

$$d\gamma = \frac{\begin{pmatrix} G_2(m_{12}m_{21} - m_{22}m_{11}) - \\ G_1(m_{22}m_{31} - m_{32}m_{21}) \end{pmatrix}}{\begin{pmatrix} (m_{13}m_{21} - m_{23}m_{11})(m_{22}m_{31} - m_{32}m_{21}) - \\ (m_{23}m_{31} - m_{33}m_{21})(m_{12}m_{21} - m_{22}m_{11}) \end{pmatrix}} \tag{11}$$

In above formula, coefficient G is as following:

$$G_1 = m_{14}m_{21}dN_{11} + m_{15}m_{21}dN_{12} + m_{16}m_{21}dN_{13} - m_{24}m_{11}dN_{21} - m_{25}m_{11}dN_{22} - m_{26}m_{11}dN_{23}$$

$$G_2 = m_{25}m_{31}dN_{22} + m_{26}m_{31}dN_{23} - m_{34}m_{21}dN_{31} - m_{35}m_{21}dN_{32} - m_{36}m_{21}dN_{33}$$

We assume the errors of the norm vectors of straight line features have been modeled as a uniform distribution. Formula (9) (10) (11) analysis how the quantization errors propagate and it obtain the relationship between the errors from rotation angle α, β, γ and the errors from normal vector $N_i = (N_{i1}, N_{i2}, N_{i3})$ of the explanation plane in closed-form solutions form.

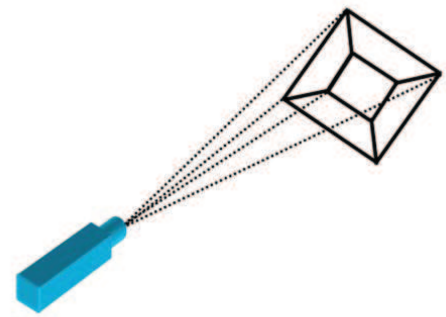

Figure 2: Pose measurement model of quadrangular frustum pyramid

4 Optimum line configuration for quadrangular frustum pyramid location model

Optimization function for the optimum line configuration of location model with respect to the camera is expressed as sum of absolute value for rotation angle:

$$\mathrm{F} = \mathrm{Abs}(d\alpha) + \mathrm{Abs}(d\beta) + \mathrm{Abs}(d\gamma) \tag{12}$$

In practical application, we can use it to determine the optimum line configuration for given location model with respect to camera. When the sum of the errors for the pose estimation is minimum, we can determine the optimum line configuration on location model with respect to the camera. The analysis can select the best line configuration on location model for pose estimation, thus it can increase the accuracy for pose estimation.

To test the validity of this method to find optimum line configuration, this paper does simulation for one quadrangular frustum pyramid model. For given model (see Fig. 2), the quantization errors have different effects on the location model with different line configuration combinations (Quantization errors have been modeled as a uniform distribution).

As shown in Fig. 3, there are some model lines on quadrangular frustum pyramid model. They can consist of one line configuration combination from three lines of model lines. We get eight line configuration combinations when we get rid of useless line configuration which can not locate. These line configuration combinations are as shown in Fig. 3.

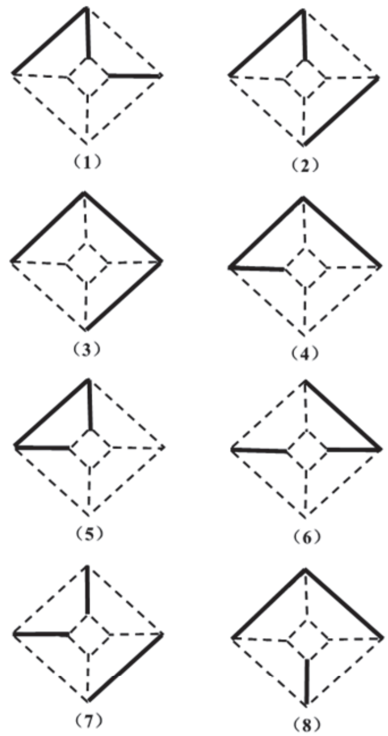

Figure 3: Line configurations on quadrangular frustum pyramid model

Table 1: Error statistical results for different line configuration combinations

Range Com	200	300	400	500	600	700
1	0.632	0.737	0.84	1.047	2.057	2.062
2	7.028	8.578	9.004	10.61	11.082	12.16
3	12.964	15.964	18.964	20.964	23.561	26.394
4	2.533	3.767	4.767	4.964	7.683	9.683
5	0.476	0.512	0.675	0.74	1.183	1.495
6	0.832	0.963	0.936	2.109	2.203	2.386
7	1.212	2.224	2.23	3.255	4.285	4.347
8	3.547	3.5	4.863	5.162	8.712	9.783

5 Experimental Results

We test quadrangular frustum pyramid model at different distance. In our simulation experiments, we choose the concrete parameters of the camera are $\begin{pmatrix} 800 & 0 & 0 \\ 0 & 800 & 0 \\ 0 & 0 & 1 \end{pmatrix}$. camera concrete focus parameter is chosen as 9.85. The size of image is 512512 .We add 0.01pixel random noise to the norm vector of the image lines. The testing range is from 200mm to 700mm. We set up different testing points at the distance of 100mm. We do 15000 experiments at each testing point and analyze the value of function F. In Table 1, Range is the distance between the optical center and the location model. The value of horizontal axis corresponding(1-8)are statistic value of function F for different line configurations at different testing places. Error statistical results of different line configuration combinations on quadrangular frustum pyramid model are shown in Table 1.

We can get conclusion that accuracy for rotation angel for different line configuration combinations on location model has big disparity from statistic results. Optimum line configuration is combination (5). Then the combination which has smaller positioning error is combination (6), (1), (7), (4), (2), (8), (3). Thus we can select line configuration (5) as optimum line configuration on location model to locate in computer vision. The study for optimum line configuration on location model can increase the accuracy of pose measurement in computer vision.

6 Conclusion

Quantization errors are the primary factors that affect the accuracy of pose measurement. On basis of introduction of the characteristics for propagation of quantization errors, mathematical model for the effect of quantization errors on the accuracy of pose measurement is presented. The mathematical model of error analysis has some value in practical application. In practical engineering project, it can be used to direct the design of the intrinsic parameters of system and optimize the configuration of system. For a given location model, quantization errors have different effects on location accuracy of model with different line configuration combinations. The analysis of optimum line configuration of location model with respect to camera is an important aspect to execute vision task at high precision. This paper sets up optimization function for determining the best line configuration on location model. By experiment analysis, optimum line configuration is obtained at last. And we get statistic results for pose accuracy of rotation angel for different line configuration combinations on location mode. This method can be used to determine the optimum line configuration for an arbitrary location model. At the same time, the analysis in this paper can increase the accuracy of pose measurement for computer vision system.

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