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Practical Camera Calibration System on Mobile Platforms

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Abstract

We propose a practical camera calibration system on mobile platforms to calibrate the camera's intrinsic parameters, based on the geometrical property of the vanishing points, which are determined by two perpendicular groups of parallel lines. In this system, first, we detect and cluster the lines of the input images to compute the vanishing points. Then, we establish the intrinsic parameter constraint equations based on the perpendicular property of the vectors that connect the optical center and the vanishing points, and solve them using the least squares method. This system only requires the camera to observe a rectangular card shown in a few (at least four) different orientations. The experimental results of real images show that the proposed calibration system is robust, simple, and practicable.

Keywords: *Camera Calibration, Vanishing Point, k-means, Line detection*

1. Introduction

Camera calibration is a valuable process in the field of computer vision. It is an essential step in restoring and reconstructing the characteristics of three-dimensional space objects in two-dimensional images. This technique is widely applied in the fields of mobile robot navigation, scene reconstruction, visual surveillance, and augmented reality (AR), as well as other related areas. With the development of the smart phone, there has been extensive research into the technology of AR in mobile platforms in recent years. Owing to these developments, it is necessary to develop a calibration system that is suitable for mobile platforms.

In general, camera calibration techniques can be divided into three categories: the traditional method, the method based on the active vision technique, and the camera self-calibration method. The traditional method [1-2] can get accurate result of camera's intrinsic parameters, especially Zhang's[2] method is widely applied by reason of its flexibility and usability, but such methods require an accurate three-dimensional [1] or two-dimensional [2] calibration target; the method based on the active vision method [13-14, 19-20], a particular movement(*e.g.*, camera pure rotation, pure translation) of the camera is necessary for the calibration to be implemented, and a relatively high accuracy of experimental equipment is required; the camera self-calibration method makes use of the self-constraints of the camera for calibration. This method can further be divided into the technique based on the Kruppa's equations [3-4, 15-16], and that of the absolute quadric method [5, 12, 17-18], both of which can work without a reference calibration target. The first method that was proposed for self-calibration is based on the Kruppa's equations. These methods are difficult to implement as it results in ambiguities [11] and is not sufficiently robust. The absolute quadric method is more robust than that based on the Kruppa's equations method. Due to the projection of the dual absolute quadric is described by parameters of the internal calibration matrix of the projection

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matrices only. We can calibrate the camera by the dual absolute quadric. In both these methods, the set of corresponding points and the geometric relationship between the images must be computed by the detection and matching of feature points. Both feature point detection and feature point matching require high computational complexity. Therefore, particularly in low-performance mobile platforms, the process is extremely time-consuming.

In our system, in order to avoid such high computational complexity, we implement a camera calibration method based on the geometrical properties of the vanishing points that are determined by two perpendicular groups of parallel lines [6], a preliminary version of this paper was presented in[21], this version includes a concrete analysis. The vanishing points can be obtained from an arbitrary rectangular card, which can be a card used in everyday life (*e.g.*, credit card, business card) and is therefore easy to obtain. In comparison with other methods, our method is robust, easy to use, and requires less computation.

2. Basic Principles

2.1. Pinhole Camera Model

The pinhole camera model is a widely used model in the field of computer vision. The model is illustrated in Figure 1 below, where it can be seen that the point of intersection between the image plane and the optical axis is called the principal point. In the pinhole camera model, the distance between the principal point and the optical center can be taken to be the focal length f of the lens. A three-dimensional point in the world is projected onto an image point in the image plane by undergoing transformation through four coordinate frames: the image coordinate frame, the perspective plane coordinate frame, the camera coordinate frame, and the world coordinate frame.

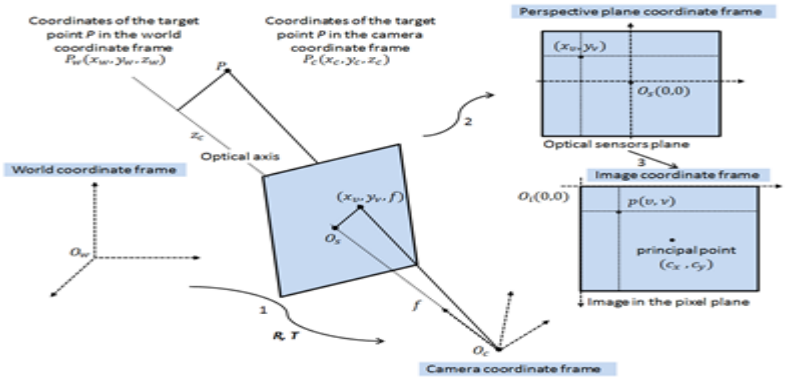

Figure 1. Pinhole Camera Model

Let the image point $p(u, v)^T$, which is located in the image coordinate frame, be the projection of the three-dimensional point $P_W(x_W, y_W, z_W)^T$ located in the world coordinate frame. Then, the projection equation can be written as:

$$\frac{1}{z_c}\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} f/d_x & s & c_x \\ 0 & f/d_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \bullet \left\{ R \bullet \begin{bmatrix} x_W \\ y_W \\ z_W \end{bmatrix} + T \right\} = K \bullet [R \quad T] \bullet \begin{bmatrix} x_W \\ y_W \\ z_W \end{bmatrix} \tag{1}$$

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Where K is the intrinsic parameters matrix of the camera; and R and T are the rotation matrix and translation matrix, respectively R and T is called the extrinsic camera parameters. In the intrinsic parameters matrix K, f is the camera's focal length, d_x, d_y are the CCD/CMOS sensor pixel's length and width, respectively, $(c_x, c_y)^T$ is the principal point, and s is a factor accounting for the skew due to non-rectangular pixels.

In most cameras, the pixels are approximately rectangular, and thus, s is very close to zero; in this paper, we suppose that s is 0. We can use f_x to represent f/d_x, and f_y to represent f/d_y. Additionally, z_c is the value corresponding to the three-dimensional world point's z_W in the camera coordinate frame.

2.2. Geometrical Property of the Vanishing Points

A set of parallel lines in the three-dimensional world is projected onto a set of converging lines in the image plane; these lines converge at a common point known as the vanishing point. The line that joins the camera center and the vanishing point of the parallel lines in the world is parallel to these parallel lines [7].

If there are two perpendicular groups of parallel lines in the world, as illustrated in Figure 2, then: $L_1 \parallel L_2, L_3 \parallel L_4, L_1 \perp L_3$; L_1 and L_2's projection l_1, l_2 intersect at vanishing point A in image plane Ω, and L_3, and L_4's projection l_3, l_4 intersect at vanishing point B. Based on the property of the vanishing point, it is known that the lines joining the optical center O and the vanishing points A and B are parallel to the respective lines corresponding to these in the world: $OA \parallel L_1, OB \parallel L_3$, then, $OA \perp OB$, and O is on a sphere with a diameter of AB.

We conclude that, if two perpendicular groups of parallel lines exist, the optical center O is on the sphere of which the diameter is the line joining the two vanishing points obtained by those parallel lines.

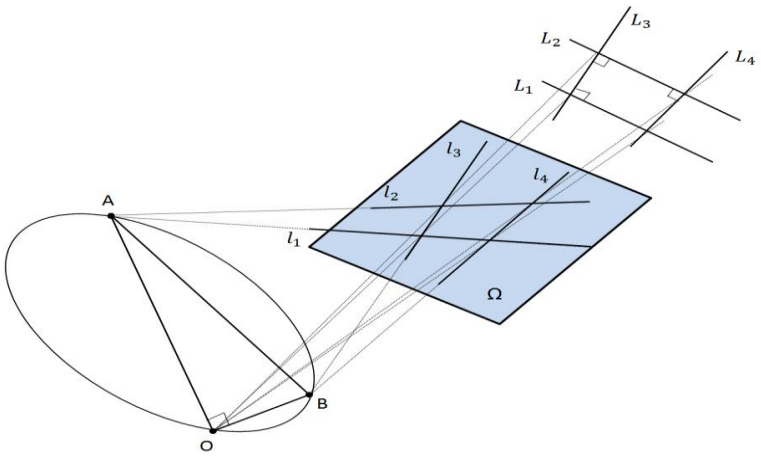

Figure 2. Geometry Model of the Ideal Projection of Two Perpendicular Groups of Parallel Lines

3. Proposed Calibration Algorithm for Mobile Platforms

Our calibration system is divided in three stages (See Figure 3). The first stage is pre-processing, for obtaining the lines, the second stage is detecting the vanishing points based on

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the lines determined in the first stage, and the last stage is calibration using the vanishing points.

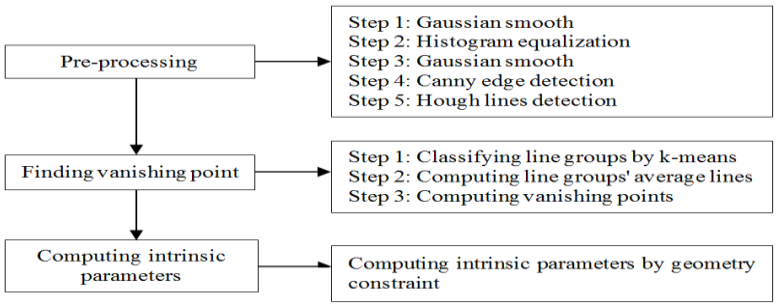

Figure 3. Overview of the Proposed Calibration System

3.1. Pre-processing

The first step in this stage is Gaussian smoothing, which is the result of blurring an image by means of a Gaussian function. This technique is widely used in graphics software, typically for reducing image noise and detail. In this paper, Gaussian smoothing is used to reduce the noise that is generated by camera's sensor, as well as to reduce bad lighting conditions to a certain extent.

Following this, we enhance the edge details of the image by increasing the global contrast by means of Histogram equalization, this method lead to better detail in the image, however, as this may increase the contrast of background noise.

In the third step, we again use Gaussian filtering to reduce the noise newly generated and minimize the little edge's influence. Thereafter, we detect the edge using the Canny algorithm [8], and finally, we detect the lines by means of Hough lines detection [9].

3.2. Vanishing Point Detection

In this stage, we use the k-means algorithm [10] to classify the lines into four groups, based on the line's angle and intercept. Thereafter, we compute the average line of each line group. In the last step, we use the average lines to calculate the vanishing points.

3.3. Camera Calibration based on Vanishing Points

In the image coordinate frame, the vanishing point coordinates obtained by the projection of the parallel lines are $A(v_A, v_A)^T$, $B(v_B, v_B)^T$. Then, the vanishing point coordinates in the camera coordinate frame are:

$$A((v_A - c_x)d_x, (v_A - c_y)d_y, f)^T \quad , \quad B((v_B - c_x)d_x, (v_B - c_y)d_y, f)^T \ .$$

The equation of the sphere of which the diameter is AB :

$$\left(x - \frac{v_A + v_B}{2} d_x + c_x d_x\right)^2 + \left(y - \frac{v_A + v_B}{2} d_y + c_y d_y\right)^2 + (z - f)^2 = \left(\frac{v_A - v_B}{2} d_x\right)^2 + \left(\frac{v_A - v_B}{2} d_y\right)^2 \tag{2}$$

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Based on the conclusion of section 2, the optical center $O(0,0,0)^T$ is on the sphere with a diameter of AB, and therefore, we substitute $O(0,0,0)^T$ into equation (2), then:

$$\left(-\frac{v_A + v_B}{2} d_x + c_x d_x\right)^2 + \left(-\frac{v_A + v_B}{2} d_y + c_y d_y\right)^2 + (-f)^2 = \left(\frac{v_A - v_B}{2} d_x\right)^2 + \left(\frac{v_A - v_B}{2} d_y\right)^2 \quad (3)$$

Simplifying equation (3):

$$\frac{(c_x - v_A)(c_x - v_B)}{f_x^2} + \frac{(c_y - v_A)(c_y - v_B)}{f_y^2} + 1 = 0 \quad (4)$$

Equation (4) is a function of the intrinsic camera parameters (f_x, f_y, c_x, c_y) and has four unknowns. It is necessary to obtain at least four images (each rectangular card image get 2 vanishing points) from different orientations.

In Hun's method [6], the lens distortion coefficient is considered, and a non-linear optimization based on Nelder-Mead simplex algorithm is used to optimize the intrinsic parameters. Due to the distortion of a mobile camera lens is very small and the low computing performance of mobile platforms, we used the method of least squares to solve the intrinsic parameters. It can reduce the computational complexity.

4. Experiments

We took four images, shown in Figure 4, using the rear camera of a Galaxy Note 2 moving it around a card so that different vanishing points could be obtained. The results of the pre-processing stage are shown in Figure 5, where we obtained straight lines around the card contours in each sample image. The results of classifying the lines are shown in Figure 6, where the classified line groups are marked with red, green, blue, and pink. The average lines are displayed in Figure 7, the average lines of each line group are marked with red, green, blue, and pink. The results of the computation of the vanishing points are given in Table 1: two vanishing points are obtained from the parameters of the average lines in each image.

The calibration results of the images in Figure 4's are listed in Table 2. In order to evaluate our method objectively, we also tested two other image data sets obtained from the same device and the result are listed in Table 2. We used Zhang's chessboard method [2] to calibrate the camera as a reference. In this test, each test data set is obtained by capturing the chessboard in 20 different orientations using the same device. Figure 8, Figure 9, Figure 10 shows the chessboard image data set. Three data sets were tested using Zhang's method, and the results are shown in Table 3. When we compare the results of our system with the results of Zhang's method, there are no significant differences between two; however, our system is more flexible.

5. Conclusion

In this paper, in accordance with the low computing performance of mobile platforms, we have presented a practical camera calibration system with low computational complexity. This system can be used to obtain the vanishing points in the image of an arbitrary rectangular card and to calibrate the intrinsic camera parameters based on these vanishing points.

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Our experiments show that this system is flexible and effective, and is superior to Zhang's method in terms of real-time performance. However, in our current implementation, the detection of the vanishing point requires a rectangle card to be used in the scene. In future studies, we plan to implement a full auto-calibration system that is independent of the rectangular card and can be used in any man-made scene.

Table 1. Vanishing Points of each Image (two vanishing points are Computed using the Parameters of the Average Lines in each Image)

	Picture 1	Picture 2	Picture 3	Picture 4
Vanishing point 1	(2664.0598, -1170.3644)	(733.19458, -834.54834)	(946.40106, 763.35248)	(-15593.582, -3253.1704)
Vanishing point 2	(-233.69971, -442.30933)	(-664.19867, 127.12403)	(1932.8491, -2226.2668)	(544.02344, -708.35468)

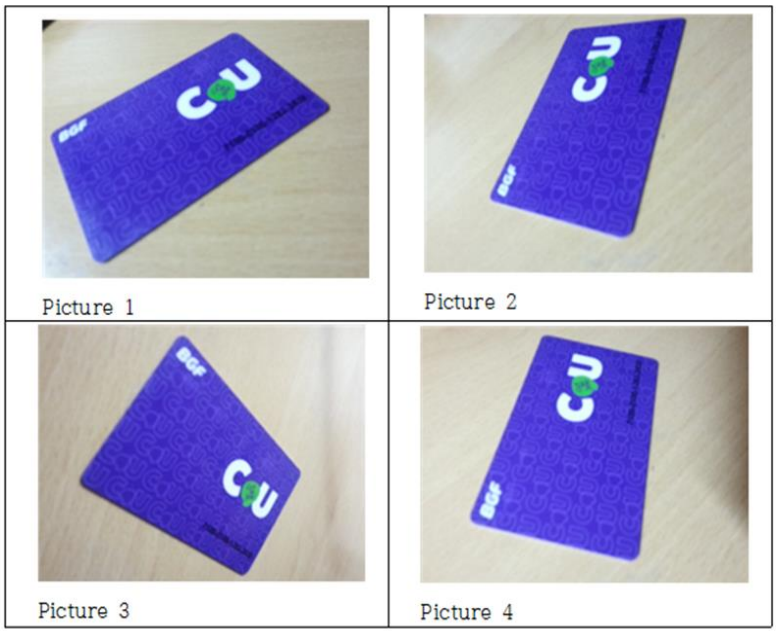

Figure 4. Test Image Sample (obtained using the Rear Camera of a Galaxy Note 2 by Moving it Around the Card; the Image Resolution is 480 × 640)

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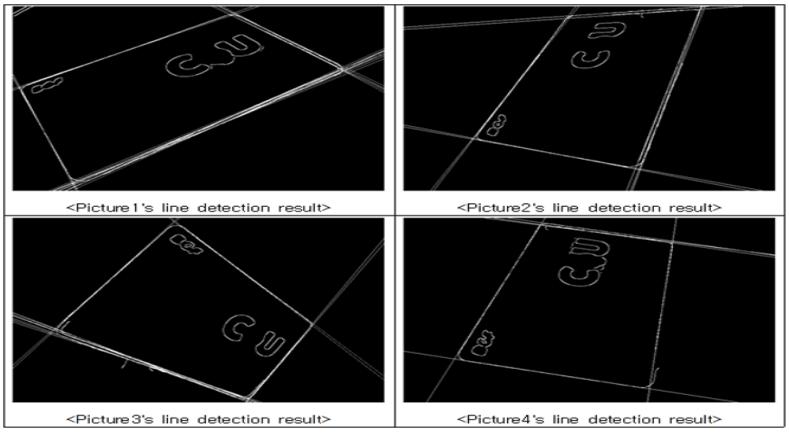

Figure 5. Results of Pre-processing (obtained the Straight Lines Around the Card Contour by Means of Hough Lines Detection; the Number of Lines is 18 in Picture 1, 9 in Picture 2, 13 in Picture 3, and 6 in Picture 4)

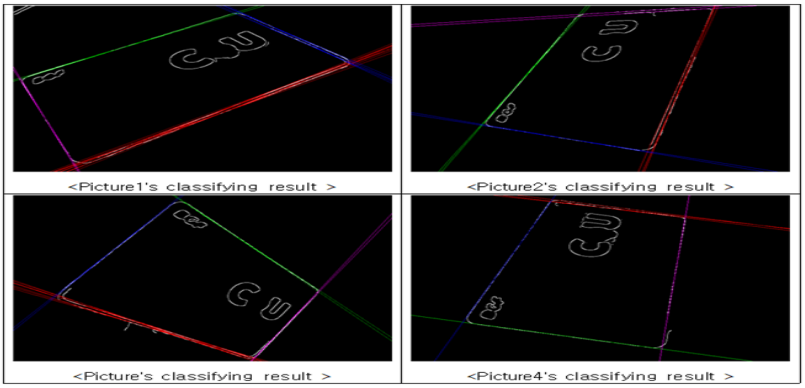

Figure 6. Results of Classifying by K-means (the Lines can be Classified into Four Groups in each Image, each of which is Marked with Red, Green, Blue, and Pink)

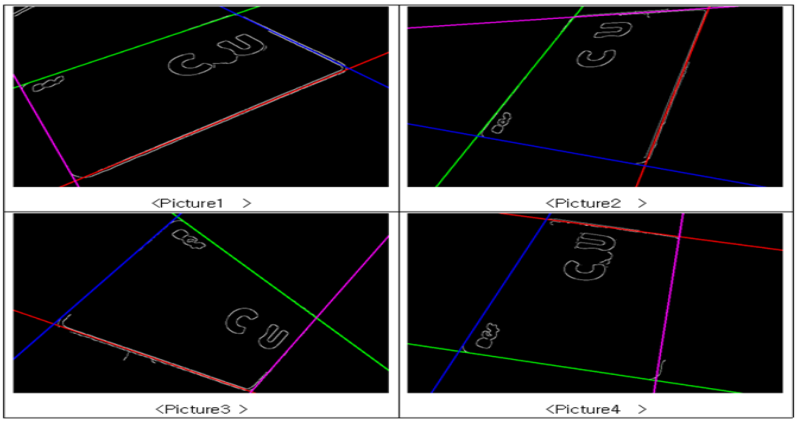

Figure 7. Average Line of each Line Group in each Image (each Average Line is Marked with Red, Green, Blue, and Pink)

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Figure 8. Chessboard Image Data Set 1 used for Zhang's Method (Obtained by Capturing Chessboard Images in 20 Different Orientations using the Same Device)

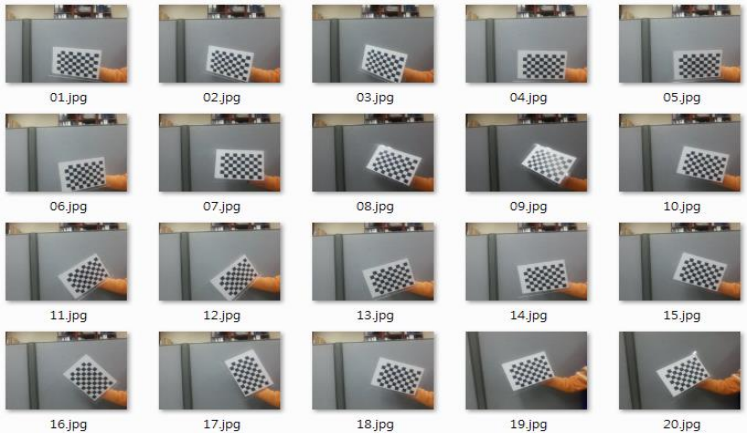

Figure 9. Chessboard Image Data Set 2 Used for Zhang's Method (obtained by Capturing Chessboard Images in 20 Different Orientations using the Same Device)

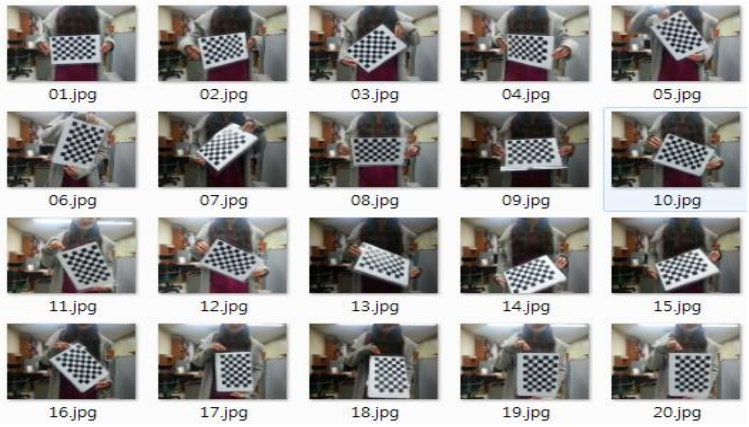

Figure 10. Chessboard Image Data Set 3 used for Zhang's Method (obtained by Capturing Chessboard Images in 20 Different Orientations using the Same Device)

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Table 2. Results of Calibration based on Vanishing Points (Test Data 1 Consists of the Four Images shown in Figure 4; Test Data 2 and 3 are the other Data Obtained by the Same Device)

Camera parameter		Test Data 1	Test Data 2	Test Data 3
focal length	f_x	528 pixels	520 pixels	525 pixels
	f_y	521 pixels	529 pixels	533 pixels
principle point	c_x	311 pixels	315 pixels	325 pixels
	c_y	247 pixels	250 pixels	244 pixels

Table 3. Results of Zhang's Method (each Test Data is obtained by Capturing Chessboard Images in 20 Different Orientations using the Same Device)

Camera parameter		Test Data1	Test Data2	Test Data3
focal length	f_x	525 pixels	524 pixels	526 pixels
	f_y	526 pixels	524 pixels	526 pixels
principle point	c_x	321 pixels	319 pixels	318 pixels
	c_y	252 pixels	250 pixels	253 pixels

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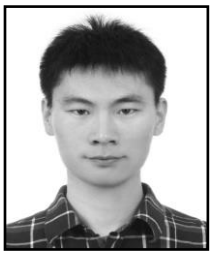

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