A Calibration Method Based on 2D Image Plane for Dual Camera System

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Abstract

Digital camera is widely used in our daily life. A wide-angle camera enables the surveillance of a large area. However, it may be difficult to perceive the detail of an object in the large area. On the other hand, a pan-tilt-zoom (PTZ) camera enables the surveillance of the object detail. However, it surveillance area may be limited when the camera zooms on a specific target. Therefore, a dual camera system is proposed in recent years by incorporating the wide-angle and PTZ cameras to complement the disadvantage of two cameras.

A calibration method is needed to enable the cooperation of two cameras. After two cameras are calibrated, the desired pan and tilt angles of a PTZ camera can be computed from the object's image coordinate of the wide-angle camera. In this paper, a new calibration method is proposed. It is simply based on the 2D image plane of the wide-angle camera. The calibration parameters for computing the pan and tilt angles are calculated from a set of calibration points separately. Every point is a pair of pan/tilt angles (p, t) and 2D coordinate (x, y). An experiment was also designed in order to evaluate the accuracy of the proposed method. The difference of pan and tilt angles of 24 test points is only 0.64 and 0.56 degree, respectively. If only considering the ten points close to the calibration points, the difference of pan and tilt angles can be decreased further to 0.27 and 0.46 degree, respectively. It shows that the proposed method is simple and accurate for the cooperation of dual-camera system.

Keywords: PTZ camera, camera calibration, moving object tracking, video surveillance.

1. Introduction

Pan-tilt-zoom (PTZ) cameras are popular used in the surveillance system currently. Its advantages include the capabilities of monitoring a large area, tracking a moving object, and providing the detail of the object. However, when a PTZ camera zooms on an object, it is unable to perceive the other objects outside the current view. Therefore, a dual-camera system is proposed in recent years by incorporating a wide-angle camera and PTZ camera for providing a better surveillance capability than a single camera.

When a moving object is found in the image of the wide-angle camera, the desired pan and tilt angles must be computed and sent to the PTZ camera for object capturing or tracking. Such cooperation of two cameras relies on a calibration method. The method provides the necessary parameters for the computation of desired pan and tilt angles from the object's coordinate in the image plane. Many calibration methods were proposed in the previous studies. Some methods are based on the common 3D world coordinate system of two cameras. The transformation from 3D coordinate system to 2D image plane is according to the operation of coordinate translation, scaling, and rotation. Others are scene-dependent. They rely on the specific features in the surveillance scene. The method cannot be used in a scene without the features. Others utilize special techniques to establish the calibration parameters of two cameras. These categories of calibration methods are presented in the next section.

In this paper, a new calibration method is proposed. Unlike the previous methods that are based on 3D world coordinate system, scene-dependent, or use special techniques, the proposed method simply based on the 2D image plane of the wide-angle camera. A set of calibration points are established and every point is a pair of pan/tilt angles (p, t) and 2D coordinate (x, y). After the calibration parameters are calculated from the set of points, the 2D coordinate of a moving object (x', y') is used to compute the desired pan/tilt angles (p', t') for controlling the PTZ camera to aim on the object. An experiment was also designed to evaluate the accuracy of the proposed method.

The rest of the paper is organized as follows.

Section 2 reviews and summarized related works. Section 3 presents the calibration method. Section 4 presents the experimental study. Section 5 gives the conclusion of our research.

2. Related Works

The calibration method of cameras is important for the cooperation of multiple cameras or dual cameras. The methods of the previous studies can be classified into three categories:

(1) *3D world coordinate system*: This category of methods is based on a common 3D world coordinate system for multiple cameras to compute the desired pan and tilt angles of PTZ camera. For example, R. Bodor *et al.* proposed a dual camera system for activity recognition [1]. The calibration is based on the inverse kinematics for computing the pan and tilt angles from the 3D world coordinate. L. Marchesotti *et al.* also proposed a dual-camera system for face detection [5]. The calibration method is based on Tsai's method [7]. At least 12 pairs of 2D image plane and 3D world coordinates are needed to achieve precise calibration.

(2) *Scene-dependent*: This category of methods is depended on some specific features in the scene. For example, K. T. Song and J. C. Tai proposed a calibration method for traffic monitoring [6]. It is mainly based on the parallel lane markings and the lane width to compute the camera parameters. I. H. Chen and S. J. Wang also proposed a novel and efficient method for the calibration of multiple PTZ cameras [2]. The PTZ cameras are mounted on the ceiling of indoor environment. Therefore, the calibration is based on the tilt angle and altitude of PTZ cameras. The image processing technique is also used to infer the relative positioning and orientation among multiple PTZ cameras. However, the calibration method is invalid when PTZ cameras are not mounded on the ceiling.

(3) *Special technique*: This category of methods utilizes special techniques for camera calibration. For example, J. Davis and X. Chen proposed a more complete calibration method for pan-tilt cameras [3]. Authors use an improved model of camera to provide a large virtual calibration target by tracking the motion of a LED point feature. However, it is troublesome to obtain the calibration data for the variety of cameras. C. H. Lee *et al.* also proposed a manual calibration method [4]. An image registration technique is used to establish the panning, tilting, and zooming tables separately. However, the construction of the pan/tilt/zoom tables is also a problem for variety types of cameras.

In this paper, a calibration method is proposed simply based on 2D image plane without considering the 3D world coordinate system for dual camera system. The method is also scene-independent and a general calibration method for the variety dual camera system.

3. The Calibration Method

The method is used to obtain the values of desired parameters for the computation of pan/tilt angles from a coordinate on the 2D image plane. The pan and tilt operation of a PTZ camera is independent. Thus, the calibration of pan and tilt angles are processed separately. Three points are needed for the pan or tilt calibration. That is, total six calibration points are used in the method. Every point is a pair of a coordinate (x, y) on the 2D image plane and the corresponding pan/tilt angles (p, t) of PTZ camera. The process of the calibration method is shown in the Figure 1.

Assume the three calibration points are denoted as $\{(x_i, y_i), (p_i, t_i)\}, \text{for } 1 \le i \le 3$. The evaluation of calibration parameters and pan or tilt angles are presented in the following subsections.

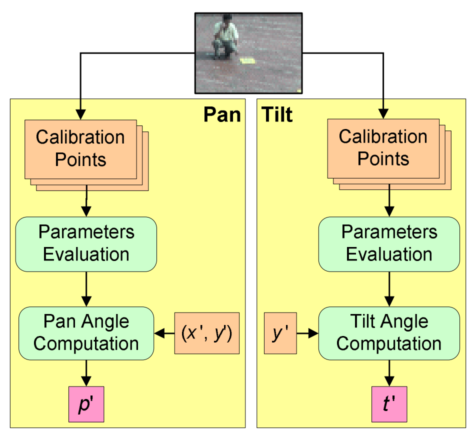

Figure 1: The calibration process

3.1 The calibration of pan angle

The model of the pan angle computation is shown in Figure 2. Assume the camera position is marked as O and its sight line of zero pan angle exists α degrees with the y-axis of the 2D image coordinate system as shown in the figure. Three calibration parameters, x_0, y_0, and α, are evaluated firstly. Then, the desired pan angle p'

for a given (x', y') can be computed based on the three parameters.

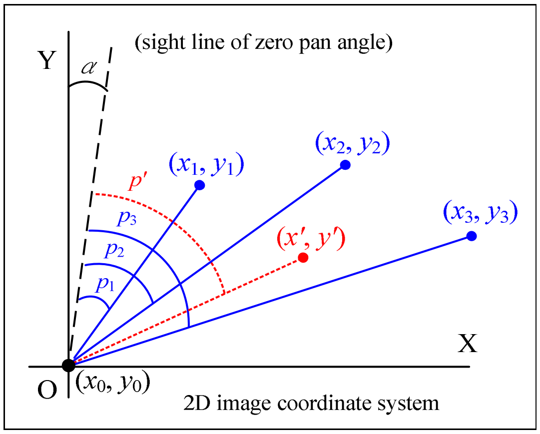

Figure 2: The model of pan angle computation

Firstly, the equation for calculating $\cot(p_1+\alpha)$ can be expressed in Eq. (1).

$$\cot(p_1+\alpha)=\frac{y_1-y_0}{x_1-x_0}$$
$$\frac{y_1-y_0}{x_1-x_0}=\frac{\cot(p_1)\cot(\alpha)-1}{\cot(p_1)+\cot(\alpha)} \qquad (1)$$

Similarly, the equations for calculating $\cot(p_2+\alpha)$ and $\cot(p_3+\alpha)$ are shown in Eq. (2).

$$\frac{y_2-y_0}{x_2-x_0}=\frac{\cot(p_2)\cot(\alpha)-1}{\cot(p_2)+\cot(\alpha)}$$
$$\frac{y_3-y_0}{x_3-x_0}=\frac{\cot(p_3)\cot(\alpha)-1}{\cot(p_3)+\cot(\alpha)} \qquad (2)$$

The three parameters can be calculated from the above three equations. After the three parameters, x_0, y_0, and α, are evaluated, the desired p' for a given (x', y') can be computed based on Eq. (3).

$$\frac{y'-y_0}{x'-x_0}=\cot(p'+\alpha)$$
$$p'=\operatorname{arccot}\left(\frac{y'-y_0}{x'-x_0}\right)-\alpha \qquad (3)$$

3.2 The calibration of tilt angle

The model of the tilt angle computation is shown in Figure 3. Assume the camera position is marked as O, its height is h, and its sight line of zero tilt angle exists θ degrees with the horizontal line as shown in the figure. The parameter h is a hypothetical value for tilt calibration but not the physical height of the camera. Two calibration parameters, h and θ, are evaluated firstly. Then, the desired tilt angle t' for a given y' can be computed based on the two parameters.

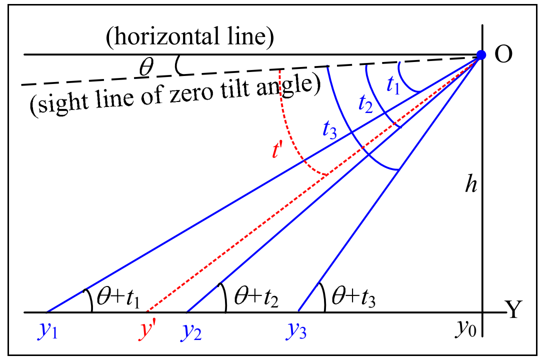

Figure 3: The model of tilt angle computation

According to the trigonometric formula, the calculation of the length from y_1 to y_2, denoted as $\overline{y_1y_2}$, is shown in Eq. (4).

$$\overline{y_1y_0}=|y_1-y_0|=\cot(\theta+t_1)\times h$$
$$\overline{y_2y_0}=|y_2-y_0|=\cot(\theta+t_2)\times h \qquad (4)$$
$$\overline{y_1y_2}=\overline{y_1y_0}-\overline{y_2y_0}$$
$$=[\cot(\theta+t_1)-\cot(\theta+t_2)]\times h$$

The equation of $\overline{y_1y_2}$ can be expanded further by using the trigonometric formula as shown in Eg. (5).

$$\frac{\overline{y_1y_2}}{h}=\frac{\cot(\theta)\cot(t_1)-1}{\cot(\theta)+\cot(t_1)}-\frac{\cot(\theta)\cot(t_2)-1}{\cot(\theta)+\cot(t_2)} \qquad (5)$$
$$=\frac{[\cot(t_1)-\cot(t_2)]\cot(\theta)^2+\cot(t_1)-\cot(t_2)}{\cot(\theta)^2+[\cot(t_1)+\cot(t_2)]\cot(\theta)+\cot(t_1)\times\cot(t_2)}$$

Let $m_1=\cot(t_1)-\cot(t_2)$, $n_1=\cot(t_1)+\cot(t_2)$, and $k_1=\cot(t_1)\times\cot(t_2)$, the above equation is rewritten as Eg. (6).

$$\frac{\overline{y_1y_2}}{h}=\frac{m_1\left[\cot(\theta)^2+1\right]}{\cot(\theta)^2+n_1\cot(\theta)+k_1} \qquad (6)$$

Similarly, let $m_2=\cot(t_2)-\cot(t_3)$, $n_2=\cot(t_2)+\cot(t_3)$, and $k_2=\cot(t_2)\times\cot(t_3)$, the computation of $\overline{y_2y_3}$ is shown in Eg. (7).

$$\frac{\overline{y_2y_3}}{h}=\frac{m_2\left[\cot(\theta)^2+1\right]}{\cot(\theta)^2+n_2\cot(\theta)+k_2} \qquad (7)$$

Then, Eq. (6) is divided by Eq. (7). The result is shown in Eq. (8).

$$\frac{\overline{y_1y_2}}{\overline{y_2y_3}}=\frac{m_1\left[\cot(\theta)^2+1\right]}{\cot(\theta)^2+n_1\cot(\theta)+k_1}\times\frac{\cot(\theta)^2+n_2\cot(\theta)+k_2}{m_2\left[\cot(\theta)^2+1\right]}$$
$$=\frac{m_1\cot(\theta)^2+m_1n_2\cot(\theta)+m_1k_2}{m_2\cot(\theta)^2+m_2n_1\cot(\theta)+m_2k_1} \qquad (8)$$
$$\left(m_1\overline{y_2y_3}-m_2\overline{y_1y_2}\right)\cot(\theta)^2+$$
$$\left(m_1n_2\overline{y_2y_3}-m_2n_1\overline{y_1y_2}\right)\cot(\theta)+$$
$$m_1k_2\overline{y_2y_3}-m_2k_1\overline{y_1y_2}=0$$

Let $\gamma = m_1\overline{y_2 y_3} - m_2\overline{y_1 y_2}$, $\lambda = m_1 n_2\overline{y_2 y_3} - m_2 n_1\overline{y_1 y_2}$, and $\mu = m_1 k_2\overline{y_2 y_3} - m_2 k_1\overline{y_1 y_2}$, the above equation can be rewritten as Eg. (9).

$$\gamma\cot(\theta)^2 + \lambda\cot(\theta) + \mu = 0 \quad (9)$$

Therefore, the solutions of Eg. (9) are shown in Eg. (10).

$$\cot(\theta) = \frac{-\lambda \pm \sqrt{\lambda^2 - 4\gamma\mu}}{2\gamma} \quad (10)$$

There are two solutions for Eg. (10). However, the negative solution is not considered in the calibration model. The equations of two parameters θ and h are shown in Eg. (11).

$$\begin{aligned}
&\theta = \operatorname{arccot}\left(\frac{-\lambda + \sqrt{\lambda^2 - 4\gamma\mu}}{2\gamma}\right)\\
&\overline{y_1 y_2} = \overline{y_1 y_0} - \overline{y_2 y_0} = [\cot(\theta + t_1) - \cot(\theta + t_2)] \times h\\
&h = \frac{\overline{y_1 y_2}}{\cot(\theta + t_1) - \cot(\theta + t_2)}\\
&\overline{y_1 y_0} = |y_1 - y_0| = \cot(\theta + t_1) \times h\\
&y_0 = y_1 - \cot(\theta + t_1) \times h
\end{aligned} \quad (11)$$

Then, the desired tilt angle *t'* for a given *y'* can be computed according to the Eg. (12).

$$\begin{aligned}
&\overline{y' y_0} = y' - y_0 = \cot(\theta + t') \times h\\
&t' = \operatorname{arccot}\left(\frac{\overline{y' y_0}}{h}\right) - \theta
\end{aligned} \quad (12)$$

4. Experimental Study

A prototype was implemented by using Visual Studio 2005 in order to evaluate the accuracy of the proposed calibration method. Two cameras were installed on our building and focus on a square, called red-brick square. The model of the wide-angle camera is AXIS-207 and the model of the PTZ camera is AXIS-214 with 18X optical zoom as shown in Figure 4.

Figure 4: The cameras used in the experiment

The experiment is separated into three steps. Firstly, the prototype is used to setup calibration points and generate the desired parameters for computing the pan and tilt angles. Secondly, 24 points are chosen to cover the whole square. Secondly, the coordinate of every point is used to compute the pan and tilt angles according to the proposed method. The computed angles are recorded and sent to the PTZ camera. Finally, the point is adjusted manually to the center of the view of PTZ camera, the correct pan/tilt angles are recorded, too. The difference between the computed angles and correct angles of pan and tilt are calculated separately.

Five points, denoted as C_1~C_5, for coordinate transformation are shown in Figure 5. The image coordinates and corresponding pan and tilt angles of five points are recorded. Then, a set of three points for the tilt computation, C_1, C_2, and C_3, are chosen about a vertical line. Another set of three points, C_1, C_4, and C_5, are chosen to form an triangle for the pan calibration.

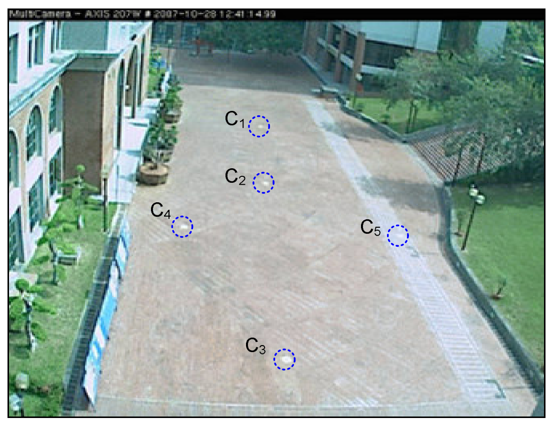

Figure 5: Five calibration points

The 24 points chosen for evaluating the accuracy of the proposed method are shown in Figure 6. Every point is placed a 32cm×32cm piece to mark its location. These points are similar to a grid which covered the whole square in order to make the experiment more valid.

An example of difference computation is also shown in Figure 7 to depict the difference computation for every testing point. When the computed pan and tilt angles are sent to the PTZ camera, the testing point, i.e., the 32cm×32cm piece, may be not in the center of the camera image as shown in Figure 7(a). Then, the camera is adjusted manually to enable the piece in the center of the image as shown in Figure 7(b). The corresponding pan and tilt angles are deemed as correct values for difference computation.

Figure 6: The 24 testing points

(a) (b)

Figure 7: An example of difference computation (a) the image of computed pan/tilt angles (b) the image of correct pan/tilt angles

The five points and the corresponding pan/tilt angles for coordinate transformation are listed in Table 1. The experimental results of 24 testing points are listed in Table 2. The average difference of pan and tilt angles is 0.64 and 0.56 degree, respectively. The maximum difference of pan and tilt angles is 1.83 and 1.37 degrees, respectively.

Table 1: Five points for coordinate transformation

	(X, Y)	Pan	Tilt
C1	(293, 139)	9.07	-5.70
C2	(308, 208)	10.65	-11.18
C3	(350, 392)	15.60	-25.95
C4	(204, 254)	2.17	-15.53
C5	(455, 266)	23.32	-14.63

In addition, the difference of a point close to the calibration points should be small than a point far away these calibration points. Therefore, the difference of those points close to the calibration points are computed specifically and listed in Table 3. The average difference of pan and tilt angles is decreased to 0.27 and 0.46 degree, respectively.

Table 2: The experimental results of all points

No.	Pan			Tilt		
	C	A	D	C	A	D
1	3.57	2.85	0.71	-4.54	-4.54	0
2	8.08	8.06	0.02	-4.81	-4.54	0.27
3	12.7	13.34	0.65	-5.29	-4.88	0.41
4	16.79	17.87	1.08	-5.7	-4.95	0.75
5	1.02	-0.17	1.2	-6.24	-6.55	0.31
6	6.1	5.81	0.29	-6.55	-6.86	0.31
7	14.11	13.7	0.42	-7.17	-7.33	0.16
8	21.31	22.55	1.24	-8.04	-7.02	1.02
9	2.19	1.85	0.34	-9.64	-10.12	0.48
10	8.27	8.13	0.14	-9.8	-10.04	0.24
11	15.86	16.24	0.38	-10.52	-10.12	0.4
12	22.12	22.78	0.67	-10.77	-10.36	0.41
13	-2.38	-2.5	0.13	-12.85	-13.83	0.97
14	8.61	8.66	0.05	-13.42	-14.23	0.81
15	15.48	15.43	0.05	-13.91	-14.07	0.16
16	23.58	23.89	0.31	-14.89	-14.4	0.49
17	0.87	1.46	0.59	-19.3	-20.23	0.93
18	10.72	10.61	0.11	-19.47	-20.15	0.68
19	21.02	20.2	0.83	-19.98	-19.55	0.42
20	28.21	27.16	1.05	-19.64	-19.22	0.42
21	-3.7	-2.25	1.45	-23.89	-25.01	1.11
22	13.89	13.12	0.77	-25.01	-25.35	0.34
23	26.23	24.4	1.83	-24.58	-23.64	0.94
24	33.22	32.15	1.07	-23.98	-22.61	1.37
Overall (Pan)			**0.64**	Overall (Tilt)		**0.56**

(C: computed, A: actual, D: difference=|C−A|)

Table 3: The experimental results of the central area

no.	Pan			Tilt		
	C	A	D	C	A	D
6	6.1	5.81	0.29	-6.55	-6.86	0.31
7	14.11	13.7	0.42	-7.17	-7.33	0.16
9	2.19	1.85	0.34	-9.64	-10.12	0.48
10	8.27	8.13	0.14	-9.8	-10.04	0.24
11	15.86	16.24	0.38	-10.52	-10.12	0.4
13	-2.38	-2.5	0.13	-12.85	-13.83	0.97
14	8.61	8.66	0.05	-13.42	-14.23	0.81
15	15.48	15.43	0.05	-13.91	-14.07	0.16
18	10.72	10.61	0.11	-19.47	-20.15	0.68
19	21.02	20.2	0.83	-19.98	-19.55	0.42
Overall (Pan)			**0.27**	Overall (Tilt)		**0.46**

(C: computed, A: actual, D: difference=|C−A|)

The above results may be influenced by the selected calibration points. If the calibration points are close to the boundary of the image, the characteristic of the spherical lens may cause the increment of the difference. On the other hand, if the calibration points are close to each other, a coordinate of a moving object which is far away these points may have a large difference. However, if the calibration points are not ultimate, the difference is similar to our experimental results.

The experimental results also show that the proposed method is good enough for the cooperation of dual camera system. However, the location of a moving object is usually not static but changed continuously in the practical environment. The performance of the proposed method is depended on a good location prediction algorithm for providing a precise coordinate for dynamic object tracking or capturing.

5. Conclusion

In this paper, a calibration method is proposed based on the 2D image plane for the cooperation of dual camera system. It is simple and intuitive for establishing the set of calibration points. According to the experimental results, the accuracy of the proposed method is good enough for satisfying the moving object capturing or tracking in a large area. However, the current experiment only focuses on fixed locations. Some factors must be considered to fulfill this method in a practical environment with a large number of moving objects. These factors include the speed of moving objects, the scheduling of capturing jobs, shadow suppression, object occlusion, and so on. In the future works, a practical moving object capturing system based on a single wide-angle camera and multiple PTZ cameras will be implemented to illustrate the feasibility of the proposed calibration method.

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