STABILIZING IMAGE SEQUENCES TAKEN BY THE CAMCORDER MOUNTED ON A MOVING VEHICLE

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ABSTRACT

This paper presents an image stabilization technique which can be used as a very useful on-board unit of a vehicle. The proposed technique includes three steps. First, we detect two lane markings and their corresponding vanishing point from the input image. These two lane markings and their corresponding vanishing point are then used as the bases to calculate the camera motion parameters. The proposed motion estimation process can be used to solve the difficult problems such as feature point extraction and correspondence matching. In addition, the extracted road information can be used to tackle more advanced traffic problems. In the last step of our approach, a motion smoothing process is developed to remove some unwanted motion. This step is fairly important for obtaining very stable image sequences. The experimental results have shown that our method is indeed superb for stabilizing image sequences.

1. INTRODUCTION

Highly modernization of the human society has caused a number of serious problems, such as the drug problem and the traffic problem. In a well-developed city, it is difficult for the city government to build new road systems due to the limited number of available spaces. An Intelligent Transportation System (ITS), which combines various disciplines, such as control, computer architecture, communication, and signal processing, is thus introduced to "cleverly" solve the above mentioned problem. In recent years, a great number of researchers have devoted themselves to the development of an ITS [1-5]. Some important issues related to the development of an ITS are vehicle collision avoidance, intelligent cruise control, autonomous driving, and vehicle guidance. In the above mentioned issues, a vision-based system can always play an important role because it can grab richer information than other sensors. An ITS-related vision system can be placed at a crossroad to monitor different kinds of traffic activities. It can also be mounted on vehicles as an on-board unit to detect the approaching vehicles, the pedestrians, and the road signs. When a camera is mounted on a moving vehicle, the grabbed visual information will be unreliable due to the vibration of the vehicle. In this research, we shall develop a robust image stabilization technique for those vehicles equipped with an on-board vision system. Using the proposed image stabilization technique, we can make the visual information grabbed from a moving vehicle very reliable.

Usually, the mission of an image stabilization process is to remove or compensate the unwanted motion occurred in an image sequence. A typical image stabilization process usually consists of two major steps, including interframe motion detection and motion smoothing [6-10]. Interframe motion detection is usually divided into two stages: first, the correspondences of the feature points between two successive frames are estimated; second, the determined correspondences are used to calculate the required parameters for a selected motion model.

In order to establish the correspondences of some chosen feature points between two consecutive frames, feature point extraction has to be executed first. However, it is very important that the selected feature points cannot lie on a moving object. Usually, people select those points located on a horizontal line so that they won't be affected by a small camera translation. However, this kind of selection will fail if a horizontal line is not clear or the feature points located on this line are too close. There are a number of existing algorithms for correspondence matching, such as block-based full search, edge-based matching, integral projection matching, gray coded bit-plane block matching, pyramid-based matching, and optical-flow-based approach. Another important issue in interframe motion detection is the selection of an appropriate motion model. The existing motion models include 2D affine motion model, 2D rigid motion model, 2.5D model, and 3D motion model. In this paper, we propose to use lane markings together with their corresponding vanishing point as the bases to calculate the

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required motion parameters, including three for rotation and one for translation. After the camera motion is estimated, the motion smoothing process is applied to remove some non-smooth camera motion.

2. LANE MARKING DETECTION

In this section, we shall elaborate on how to detect lane markings from an image sequence. Since we assume that a vehicle is driven along two parallel lane markings, these two lane markings are projected to the left and to the right of an image, respectively. Based on our system setup, the lane markings are located at the bottom half of an image (as indicated in Fig.1). Under the circumstance, the lower left and the lower right quarter of an image are taken as the lane marking detection areas (Fig.1). First, we adopt the method proposed by Bertozzi and Broggi[11] to perform lane marking extraction. Next, the iterative algorithm proposed by Haralick and Shapiro[12] is applied to remove the noises. And then, we use middle point extraction to extract the middle points on the lane markings. Finally, the median of intercepts proposed by Kamgar-Parsi et al.[13] is applied to perform straight line fitting (Fig. 2).

2.1 Middle point extraction

After the process of noise removal, there are still some large components that do not belong to the lane markings. For deriving the equations of lines that fit in the lane markings, we have to do further processing. The middle point extraction process will filter out the above mentioned irrelevant components. In addition, the calculated middle points can be used to estimate the line equations of the lane marking.

The search strategy for the middle points is line by line from bottom to top of the search regions. The first bright points are extracted by searching from the left and the right, respectively, to the middle of the region, and the points are represented by (x_1, y) and (x_2, y) (Fig. 3). In the search process, we start from the leftmost and the rightmost points of the region if (x_1, y) and (x_2, y) are not extracted in the previous search. Otherwise, the search starts from the points obtained by expanding some pixels from (x_1, y) and (x_2, y) in the previous search. If the middle point (x', y) of (x_1, y) and (x_2, y) is the middle point on the lane marking, the distance between (x_1, y) and (x_2, y) is shorter than m and each point between (x_1, y) and (x_2, y) is bright. According to the above reasoning, the following equations are used to determine whether (x', y) is a middle point of the lane marking.

$$\begin{cases} (x_2 - x_1) < m, \\ b(x, y) = 1 \qquad \text{for } x_1 < x < x_2 . \end{cases} \tag{1}$$

If (x_1, y) and (x_2, y) satisfy the above two conditions, (x', y) is the middle point of the lane marking.

Fig. 2(d) shows the result after executing this step. It not only extracts the middle points on the lane markings but also removes most points of the non-lane marking regions.

3. CAMERA MOTION ANALYSIS

Since the lane markings and their corresponding vanishing point can be used as the bases to calculate the camera motion parameters, we shall conduct a through analysis on some camera motion-related issues based on our lane marking model. In what follows, we shall start from the derivation of camera motion, and then perspective projection. Finally, we shall derive the equation for vanishing point.

3.1 Camera motion

In this paper, we define the vehicle position in the middle of two lane markings as the origin, O_w, of the real world coordinate system. Fig.4 shows that a camera stays still in the world coordinate system without any motion. The left hand side of Fig.4 shows the situation of the X_w-Y_w plane and the right hand side shows the situation of the Y_w-Z_w plane. On the other hand, the camera motion shown in Fig.5 is to translate T_x along the X_c axis and to rotate with respect to the new set of $X_cY_cZ_c$ axes by the angles (α, β, γ), respectively. The transformation matrix that can be used to represent this motion is

$$T = R(\alpha,\beta,\gamma) \cdot Trans(T_x, 0, 0) = \tag{2}$$

$$\begin{bmatrix} \sin\alpha\sin\beta\sin\gamma + \cos\alpha\cos\gamma & \cos\alpha\sin\beta\sin\gamma - \sin\alpha\cos\gamma & \cos\beta\sin\gamma & 0 \\ \sin\alpha\cos\beta & \cos\alpha\cos\beta & -\sin\beta & 0 \\ \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma & \cos\alpha\sin\beta\cos\gamma + \sin\alpha\sin\gamma & \cos\beta\cos\gamma & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -T_x \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

3.2 Perspective projection for lane markings

A point in the scene with camera coordinate (x_c, y_c, z_c) is projected onto a point (x_i, y_i) in the image plane through perspective projection:

$$x_i = f\frac{x_c}{z_c}, \qquad y_i = f\frac{y_c}{z_c}, \tag{3}$$

where f is the focal length of the camera.

If the camera stays still (Fig.4) and the origin of the real world coordinate system is O_w, the coordinates of the origin O_c of the camera coordinate system in the real world coordinate system is $(0, 0, h)$. Since the road surface lies on the X_w-Y_w plane, all points located on this surface have a zero z_w value. A point P which is located on the road surface with coordinate (x_w, y_w, 0) can be projected onto the image plane (x_i, y_i) by using Eq.(3):

$$x_i = f\frac{x_w}{y_w}, \qquad y_i = f\frac{h}{y_w}. \tag{4}$$

Since the lane markings lie on the road surface, each point on the lane markings can be projected onto the image plane by using Eq.(4).

If the camera translates T_x along the X_c axis, the point P can be projected onto the new image plane and becomes (x_i', y_i') by using Eqs.(3) and (4):

$$x_i' = f\frac{x_w - T_x}{y_w} = x_i - \frac{T_x}{h}y_i;\; y_i' = f\frac{h}{y_w} = y_i. \tag{5}$$

Based on the Eq.(5), we can establish the point correspondences after the camera translation T_x is executed.

If the camera rotates with respect to the set of $X_cY_cZ_c$ axes by the angles (α, β, γ), respectively, the point P can be projected into the new image plane and becomes (x_i'', y_i'') by using Eqs.(3) and (4):

$$\begin{cases} x_i'' = f\dfrac{x_w(\sin\alpha\sin\beta\sin\gamma+\cos\alpha\cos\gamma)+h(\cos\alpha\sin\beta\sin\gamma-\sin\alpha\cos\gamma)+y_w\cos\beta\sin\gamma}{x_w(\sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma)+h(\cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma)+y_w\cos\beta\cos\gamma} \\ \quad = f\dfrac{x_i(\sin\alpha\sin\beta\sin\gamma+\cos\alpha\cos\gamma)+y_i(\cos\alpha\sin\beta\sin\gamma-\sin\alpha\cos\gamma)+f\cos\beta\sin\gamma}{x_i(\sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma)+y_i(\cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma)+f\cos\beta\cos\gamma} \\ y_i'' = f\dfrac{x_w\sin\alpha\cos\beta+h\cos\alpha\cos\beta+y_w(-\sin\beta)}{x_w(\sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma)+h(\cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma)+y_w\cos\beta\cos\gamma} \\ \quad = f\dfrac{x_i\sin\alpha\cos\beta+y_i\cos\alpha\cos\beta+f(-\sin\beta)}{x_i(\sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma)+y_i(\cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma)+f\cos\beta\cos\gamma} \end{cases} \tag{6}$$

Based on the Eq.(6), we can establish the point correspondences after the camera rotation is executed.

3.3 Vanishing point

The parallel lines in the real world can be projected to meet at infinity. The projection of this point into the image plane is called vanishing point. Suppose the image plane coordinate of the vanishing point is (x_v, y_v). Since we assume that the vehicle is driven along two parallel lane markings, the intersection point of the projection lines for the lane markings is the vanishing point.

When the camera stays still (Fig.4), the image plane coordinates for all points on the lane markings can be obtained by using Eq.(4). Since the vanishing point is the projection point for the infinitely far point in the real world, the coordinate y_w of the infinitely far point is far larger than the coordinate x_w of this point and h in the real world. The coordinate (x_v, y_v) of the vanishing point can be obtained by:

$$x_v \underset{y_w \gg x_w}{=} f\frac{x_w}{y_w} \approx 0, \qquad y_v \underset{y_w \gg h}{=} f\frac{h}{y_w} \approx 0. \tag{7}$$

When the camera translates T_x along the X_c axis, the new coordinate (x_v', y_v') of the vanishing point can be obtained by using Eqs.(5) and (7):

$$x_v' = x_v - \frac{T_x}{h}y_v \approx 0, \qquad y_v' = y_v \approx 0. \tag{8}$$

Thus the coordinate of the vanishing point is not affected by the camera translation.

When the camera rotates with respect to the set of $X_cY_cZ_c$ axes by the angles (α, β, γ), the new coordinate (x_v'', y_v'') of the vanishing point can be obtained by using Eqs.(6) and (7):

$$\begin{cases} x_v'' = f\dfrac{x_v(\sin\alpha\sin\beta\sin\gamma+\cos\alpha\cos\gamma)+y_v(\cos\alpha\sin\beta\sin\gamma-\sin\alpha\cos\gamma)+f\cos\beta\sin\gamma}{x_v(\sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma)+y_v(\cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma)+f\cos\beta\cos\gamma} \\ \quad \approx f\tan\gamma \\ y_v'' = f\dfrac{x_v\sin\alpha\cos\beta+y_v\cos\alpha\cos\beta+f(-\sin\beta)}{x_v(\sin\alpha\sin\beta\cos\gamma-\cos\alpha\sin\gamma)+y_v(\cos\alpha\sin\beta\cos\gamma+\sin\alpha\sin\gamma)+f\cos\beta\cos\gamma} \\ \quad \approx -f\dfrac{\tan\beta}{\cos\gamma} \end{cases} \tag{9}$$

Thus the coordinate of the vanishing point is only affected by the camera rotation parameters β and γ.

4. CAMERA MOTION ESTIMATION

In this section, we shall focus on the calculation of the camera motion parameters T_x, α, β, and γ. First, we shall use the vanishing point to calculate the parameters β and γ. Then, we shall make use of lane markings to calculate the parameters T_x and α.

4.1 Determining β and γ by the vanishing point

According to Eqs.(8) and (9), the coordinates of the vanishing point are only affected by the camera motion parameters β and γ. There, we can make use of the vanishing point to derive β and γ. According to Eq.(9), β and γ can be determined as follows:

$$\gamma = \tan^{-1}\left(\frac{x_v}{f}\right), \qquad \beta = -\tan^{-1}\left(\frac{y_v\cos\gamma}{f}\right). \tag{10}$$

4.2 Using the lane markings to calculate Tx and α

As we have mentioned earlier, there are in total four camera motion parameters, i.e., α, β, γ, and T_x. In the pervious section we have derived β and γ and used them to compensate part of the camera motion. In this section, we shall formally derive α and T_x through the help of lane markings. Suppose a point is on the lane marking and its image plane coordinate is (x_i, y_i). If the camera translates T_x along X_c and then rotates α with respect to Z_c, then the new image plane coordinate can be calculated using Eqs.(5) and (6):

$$\begin{cases} x_i' = (x_i - d\cdot y_i)\cos\alpha - y_i\sin\alpha, \\ y_i' = (x_i - d\cdot y_i)\sin\alpha + y_i\cos\alpha. \end{cases} \tag{11}$$

where $d = \frac{T_x}{h}$. Suppose the slope of a lane marking is s when the camera stays still, and the slope of a lane marking will become m when the camera translates T_x along X_c and then rotates α with respect to the new Z_c axis. Based on Eq.(11), we can further derive the following:

$$\begin{aligned} m &= \frac{0-y_t'}{0-x_t'} = \frac{(x_t - d\cdot y_t)\sin\alpha + y_t\cos\alpha}{(x_t - d\cdot y_t)\cos\alpha - y_t\sin\alpha} \\ &= \frac{(x_t - d\cdot y_t)\tan\alpha + y_t}{(x_t - d\cdot y_t) - y_t\tan\alpha} \end{aligned} \tag{12}$$

Then, based on Eq. (11), we can derive

$$\tan\alpha = \frac{m\cdot(1-d\cdot s)-s}{(1-d\cdot s)+m\cdot s} \tag{13}$$

Suppose lm_{t-1} and rm_{t-1} are the slopes of the two lane markings in the previous image after the camera motion is compensated, and l_t' and r_t' are the slopes of the two lane markings in the current image after the changes caused by β and γ are compensated. Based on Eq.(13), we can derive

$$\begin{cases} \tan\alpha = \dfrac{l_t'(1-d\cdot lm_{t-1}) - lm_{t-1}}{(1-d\cdot lm_{t-1}) + l_t'\cdot lm_{t-1}} \\ \tan\alpha = \dfrac{r_t'(1-d\cdot rm_{t-1}) - rm_{t-1}}{(1-d\cdot rm_{t-1}) + r_t'\cdot rm_{t-1}} \end{cases} \tag{14}$$

Under these circumstances, the quadratic equation of d can be derived based on Eq.(14):

$$p\cdot d^2 + q\cdot d + r = 0, \tag{15}$$

where

$$\begin{cases} p = (l_t'-r_t')\cdot lm_{t-1}\cdot rm_{t-1}, \\ q = -(l_t'-r_t')\cdot(lm_{t-1}+rm_{t-1}), \\ r = (l_t'-r_t')\cdot(1+lm_{t-1}\cdot rm_{t-1}) + (rm_{t-1}-lm_{t-1})(1+l_t'\cdot r_t'). \end{cases} \tag{16}$$

Then, we can calculate T_x and α as follows:

$$T_x = d\cdot h. \tag{17}$$

$$\alpha = \tan^{-1}\left(\frac{l_t'(1-d\cdot lm_{t-1}) - lm_{t-1}}{1-d\cdot lm_{t-1} + l_t'\cdot lm_{t-1}}\right). \tag{18}$$

5. SMOOTHING THE ESTIMATED CAMERA MOTION

After the camera motion is estimated, a motion smoothing process is applied to remove the unwanted camera motion, and then the stabilized image can be obtained. The derived four parameters consist of one translation parameter, T_x, and three rotation parameters, α, β, and γ. Among these four parameters, the translation is purely caused by the vehicle motion, and it is completely irrelevant to vehicle vibration. Thus we remove the camera rotation and maintain the camera translation. In this process, we determine the smoothed rotation angle and then perform an image warping process to transform the current unstable image into a stabilized image.

5.1 Determining smoothed rotation angle

The estimated camera rotation is not really unwanted because part of the camera rotation is caused by the vehicle smoothed motion. If the estimated camera rotation is completely removed, part of the camera rotation caused by the vehicle smoothed motion is also removed. Thus the smoothed rotation angle determination process can be applied to determine the smoothed camera rotation from the estimated camera rotation.

Suppose x_t is the calculated rotation parameter in the current image, and x_{t-2}' and x_{t-1}' are the smoothed rotation parameters in the pervious two images. The possible smooth parameter $(2x_{t-1}' - x_{t-2}')$ is calculated by using extrapolation. Under these circumstances, we can predict the smoothed parameter x_t' by

$$x_t' = (1-k)\cdot(2x_{t-1}' - x_{t-2}') + k\cdot x_t, \tag{19}$$

where $k = e^{-(|x_t - x_{t-1}'|)^{\frac{1}{2}}}$ is the weight.

Based on Eq.(19), we can determine the smoothed camera rotation parameters α', β', and γ' by the calculated camera rotation parameters α, β, and γ, respectively.

6. EXPERIMENTAL RESULTS

We have conducted a series of experiments to test the effectiveness of our stabilization technique. The contents of the conducted experiments included lane marking detection, camera motion estimation, motion smoothing, and real image sequences stabilization.

The input image sequences adopted were color image sequences taken from a camera, and each image frame size was 320×240. These image sequences were taken by a camera at different time instances and at different road sections. We shall elaborate the results of the above mentioned experiments in the following.

Fig.6 shows a set of images taken at different time instances in a day. It is clear that the proposed lane marking detection algorithm was able to detect correct results either at daytime (a)-(c), or at night (d)-(f).

In the experiments of camera motion estimation, one cannot correctly estimate the camera motion parameters if two consecutive real images were used. Therefore, we used simulated lane markings to achieve the goal. Tables 1 and 2 illustrate the proposed technique can correctly estimate the camera motion parameters.

After the motion parameters were calculated, we then applied the motion smoothing process to smoothen the parameter curves. Fig.7 illustrates the curves of α, β, and γ before and after applying the motion smoothing process. The experimental results of the tests on real image sequences are hard to display. In these results, most of the image sequences used for testing were really stabilized, but some cases failed possibly due to the errors introduced by the lane marking determination process. However, an average 95% success rates is still an encouraging outcome due to the simplicity of the algorithm.

7. CONCLUSION

We have proposed an image stabilization technique which can be used as a very useful on-board unit of a vehicle. The proposed technique was composed of three major steps: lane marking detection, camera motion estimation, and motion smoothing. The proposed motion estimation process is useful for solving the difficult problems such as feature point extraction and correspondence matching. The experimental results have shown that our image stabilization technique is indeed superb.

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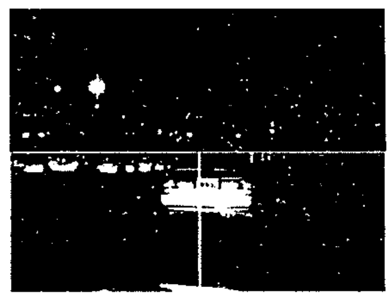
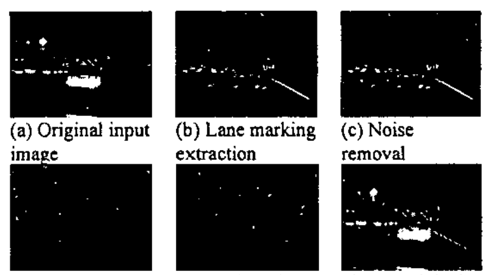


Fig.1 Lane marking detection areas



(a) Original input image
(b) Lane marking extraction
(c) Noise removal
(d) Middle point extraction
(e) Straight line fitting
(f) The original image with detected lane markings

Fig.2 Lane marking detection

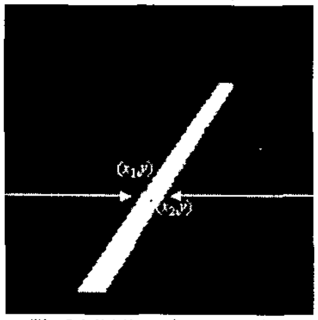


Fig.3 Middle point extraction

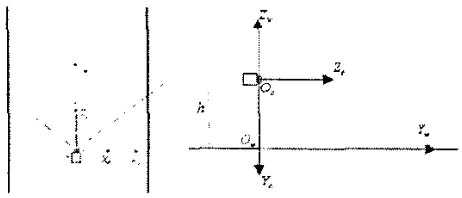


Fig.4 A camera without any motion

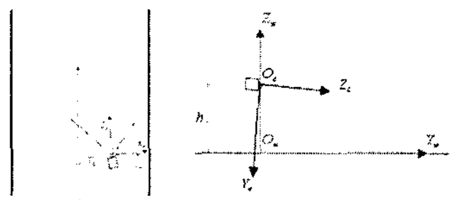
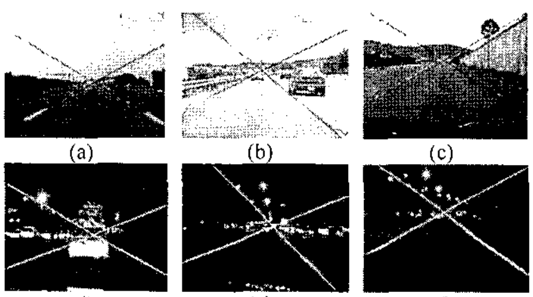


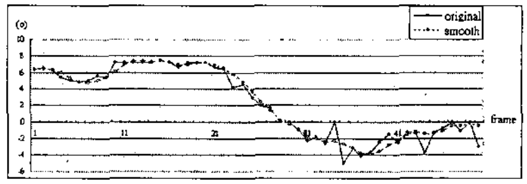
Fig.5 A camera with certain motion



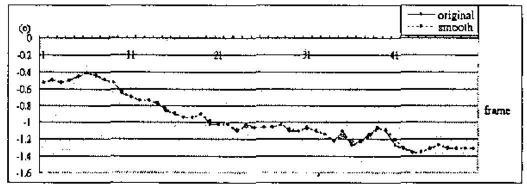
(a) (b) (c)

(d) (e) (f)

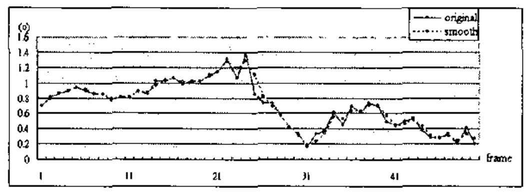
Fig.6 Lane marking detection at different time instances in a day. (a)-(c), the images taken at daytime. (d)-(f), the images taken at night.



(a) The curve of motion parameter α



(b) The curve of motion parameter β



(c) The curve of motion parameter γ

Fig.7 The curves of α, β, and γ, before and after applying the motion smoothing algorithm.

T_x=0，α=0°，β= -10° ~10°，γ= -10° ~10°			
The average error in β	0.019712°	The average error in γ	0.022273°
The maximum error in β	0.040042°	The maximum error in γ	0.035346°

Table 1 The estimated errors of β and γ when T_x and α were fixed.

β=0°，γ=0°，T_x= -1m ~1m，α= -10° ~10°			
The average error in T_x (m)	0.0000015	The average error in α	0.0000284°
The maximum error in T_x (m)	0.000317	The maximum error in α	0.005591°

Table 2 The estimated errors of T_x and α when β and γ were fixed.