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Robust Inverse Perspective Mapping Based on Vanishing Point

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Abstract— **Vision-based road signs detection and recognition has been widely used in intelligent robotics and automotive autonomous driving technology. Currently, one-time calibration of inverse perspective mapping (IPM) parameters is employed to eliminate the effect of perspective mapping, but it is not robust to the uphill and downhill road. We propose an automatic inverse perspective mapping method based on vanishing point, which is adaptive to the uphill and downhill road even with slight rotation of the main road direction. The proposed algorithm is composed of the following three steps: detecting the vanishing point, calculating the pitch and yaw angles and adopting inverse perspective mapping to obtain the "bird's eye view" image. Experimental results show that the adaptability of our inverse perspective mapping framework is comparable to existing state-of-the-art methods, which is conducive to the subsequent detection and recognition of road signs.**

I. INTRODUCTION

With the rapid development of modern road transport, vehicle has became increasingly popular for people's daily life and brought a lot of convenience. However, traffic safety has become an unavoidable problem with a serious impact on people's personal and property safety. In recent years, research and exploration on unmanned automatic driving assistance systems has become a hot research topic. All of these studies are inseparable from the understanding and application of road traffic signs information. Understanding of road traffic signs information (the lane, crosswalks, stop lines, instruction arrows, etc.) mainly contains the detection and recognition steps. Wherein the detection includes feature extraction and model fitting [1]. The model fitting use the edge, width, shape and color information of the road sign to determine the exact location of road signs.

In road traffic signs detection, there are some interferences that may affect the accuracy of road traffic sign location: too strong or too weak light conditions will cause interference on gray values of the road signs; obstructions (such as the vehicle in the front) would block the road traffic signs; pinhole camera perspective effect also makes some deformation on the road traffic signs, which results in the same size object become smaller with increasing distance along the direction of the optical axis of the camera. These interferences make road traffic signs detection very challenging.

A common method to eliminate the perspective effect of the image is inverse perspective mapping. Inverse perspective mapping is the inverse process of perspective mapping (PM). It maps the image information from the image coordinate system to the real world coordinate system and forms a three-dimensional "bird's eye view" of the road image. By establishing an appropriate world coordinate system we can make the real road plane correspond to the plane (Z=0) in the three-dimensional world coordinate system, thereby obtaining a top view of the real road surface. After eliminating the effect of perspective, more invariant information of the road traffic signs can be obtained and contribute to subsequent detection and recognition.

Inverse perspective mapping has been widely used in understanding road traffic signs information. Borkar *et al.* [2] use inverse perspective mapping method to eliminate the effect of perspective, and then detect the lane in night condition with a cascade method. Aly *et al.* [3] first eliminate the effect of perspective by inverse perspective mapping, and then use horizontal and vertical gaussian kernel filter to enhance the contrast between road traffic signs and backgrounds. Finally they adopt Hough line detection and RANSAC fitting to locate lane markings. Deng *et al.* [4] propose to use edge extraction and B-Spline fitting to detect the lane makings after the inverse perspective mapping pretreatment. Lin *et al.* [5] propose a parking assist system based on inverse perspective mapping that can show rear of the car image in real time. Wang *et al.* [6] adopt inverse perspective mapping, Haar wavelet feature extraction and SVM classification methods to achieve detection and recognition of indicating arrow markings. Meanwhile, the inverse perspective mapping used in vehicle flow detection [7] and road obstacle distance detection [8] has also achieved good results.

Currently, the inverse perspective mapping is mostly used with fixed calibration parameters. However, due to the impact of road slope (uphill or downhill) and movement of the car in the complex road environment, it results in some variation on the pitch angle and yaw angle of the camera. Vanishing point [9] is one of the important features of an image as the result of perspective effect. Due to the structural characteristics of the vanishing point, there is some relationship between vanishing point coordinate and the pitch and yaw angle. So for each frame, the vanishing point can be used to calculate the deflection angle (the pitch and yaw angle) automatically.

In this paper, we propose an automatic inverse perspective mapping method based on vanishing point. It does not only eliminate the "horizontal line bending" error [10] caused

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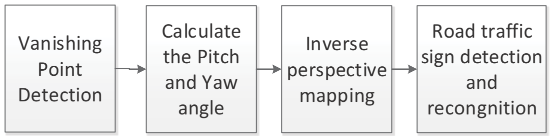


Fig. 1. Flow diagram of automatic perspective elimination

by inverse perspective mapping method [11], but also can calibrate the slight rotation (the main road direction and the world coordinate system axis are not perpendicular) of the main road direction caused by the yaw angle. This method mainly contains three steps: detecting the position of the vanishing point, calculating the deflection angle based on the vanishing point and using inverse perspective mapping to further eliminate perspective effect. After that, subsequent detection and recognition of road traffic signs could be performed on the IPM result. The specific process is shown in Fig. 1.

The paper is organized as follows: section II presents the basic principles and processes of inverse perspective mapping; section III describes the pitch and yaw angle calculation based on the vanishing point; section IV shows the comparison results of different inverse perspective mapping methods; section V draws the conclusions.

II. Inverse Perspective Mapping

With the rapid development of intelligent robotics and autonomous driving technology, camera sensors has been widely used. The image captured by the camera is a projection of three-dimensional picture of the world coordinate system to the two-dimensional image coordinate system, which is similar with the physical pinhole imaging model. Mathematically, this process is called perspective mapping, while the inverse process is called inverse perspective mapping. In terms of road environment-aware applications, the camera is mostly mounted on the top of the car or near the rear-view mirror.

We choose the actual road conditions to build the world coordinate system to represent the actual three-dimensional space (see Fig. 2 a)) and establish the final camera imaging coordinate system to represent the two-dimensional image space. A common approach to install the camera should make a initial pitch angle θ_c between the direction of camera optical axis direction and the main road direction in the Y-Z plane (see Fig. 2 c)). However, in practical scenarios, due to the uneven road surface or in the uphill and downhill case, there is a pitch angle variation $\delta\theta$ equal to the road plane slope angle, so the total pitch angle θ contains two part: road plane slope $\delta\theta$ and camera pitch angle θ_c. Also, there exists a yaw angle γ (see Fig. 2 b)) between the travel direction of the car and the main road direction.

Perspective deformation in natural scenes makes the road signs detection much more difficult. We can usually adopt inverse perspective mapping method to map the image from the image coordinate system to the actual world coordinate system, and obtain the "bird-eye view" of the road plane.

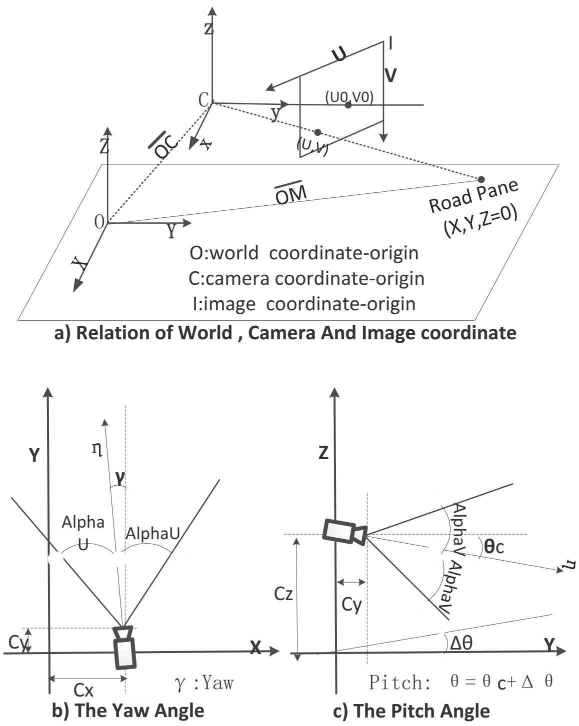


Fig. 2. Coordinate system and the deflection angle, a) shows the relationship between world coordinate system, camera coordinate system and image coordinate system, b) shows the yaw angle γ and c) shows the pitch angle θ.

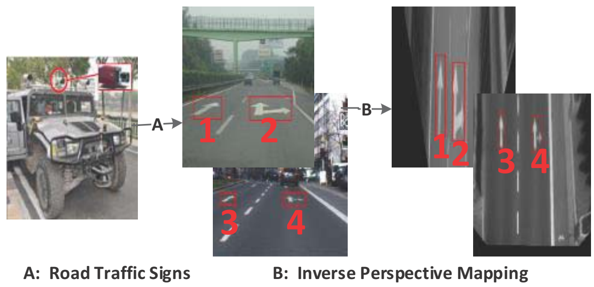


Fig. 3. Effects of inverse perspective mapping.

The result image processed by inverse perspective mapping method has more invariant information of road traffic signs that is helpful for the subsequent detection and recognition (see Fig. 3). Compared to the original image, the "bird-eye view" image has some merits [12]: first, any processing result on the "bird-eye view" image can be related to actual physical meaning in 3D world; second, lane marks are almost aligned in the same direction on the "bird-eye view" image, which brings convenience for image processing.

The inverse perspective mapping method map the points in the image coordinate system to real world coordinates with the camera position, the pitch angle, the yaw angle and the camera angular aperture in the vertical and horizontal directions. A linear interpolation method with the original image and the result real world coordinates could get the "bird's eye view" image without perspective deformation. The translation between the two-dimensional image coordinate and the three-dimensional world coordinate can be described in (1) and (2).

$$\begin{cases} rFactor = (1 - \frac{2U}{M-1}) \times \tan(AlphaV) \\ cFactor = (1 - \frac{2V}{N-1}) \times \tan(AlphaU) \end{cases} \quad (1)$$

$$\begin{cases} X_0(r,c) = C_z \times \frac{1 + rFactor \times \tan(\theta)}{\tan(\theta) - rFactor} + C_x \\ Y_0(r,c) = C_z \times \frac{cFactor \div \cos(\theta)}{\tan(\theta) - rFactor} + C_y \end{cases} \quad (2)$$

Where $(X, Y, Z = 0)$ is the road surface in the world coordinate system; (U, V) is the coordinate in the image coordinate system; $X_0(r,c)$ and $Y_0(r,c)$ represent the horizontal and vertical coordinates of the world coordinate system mapped from the image coordinate system; (M, N) is the width and height of the image; $C = (C_x, C_y, C_z)$ is the camera position coordinate in the real world coordinate. It is worth noting that choosing the right world coordinate system can make $C_x = C_y = 0$ and C_z is the camera height from the road plane. The $AlphaV$ and $AlphaU$ represent the camera angular aperture in the vertical and horizontal directions, they can be calculated by the the camera's focal length F, the height H and width W of the camera's light-sensitive components as (3).

$$\begin{cases} AlphaU = \arctan(\frac{W}{2 \times F}) \\ AlphaV = \arctan(\frac{H}{2 \times F}) \end{cases} \quad (3)$$

Equation (1) and (2) describe the transformation from a pixel position in the image coordinate system to the world coordinate system. After the linear interpolation we are able to get the results of the inverse perspective mapping. Equation (1) and (2) are primarily responsible for correcting the pitch angle, thereby removing the effect of perspective. As can be seen from equation (1) and (2), X-axis coordinate of the world coordinate system is only related with the value of U-axis in the image coordinate system, so a row in the image coordinate system is mapped to the same row in the world coordinate system that solves the "horizontal line bending" [11] problem fundamentally.

Equation (1) and (2) eliminate the perspective effect mainly caused by the pitch angle. But in fact, when the car is moving, the main road direction may have a little rotation due to the slight yaw angle. We need to compensate for the yaw angle to eliminate this rotation phenomenon. To make the main road direction in inverse perspective mapping result more parallel with V-axis in the image coordinate system, we use the compensation equation (4) as follows.

$$\begin{cases} X(r,c) = X_0(r,c) \times \cos(\gamma) + Y_0(r,c) \times \sin(\gamma) \\ Y(r,c) = X_0(r,c) \times (-\sin(\gamma)) + Y_0(r,c) \times \cos(\gamma) \end{cases} \quad (4)$$

$X(r,c)$ and $Y(r,c)$ represent the horizontal and vertical coordinates of the world coordinate system mapped from the image coordinate system with compensation of the γ angle. Part of the image above the vanishing point V-axis would be discard because they are too far from the camera mounted on the car. Then we can focus on the analysis and understanding the effective area of the image in the lower half of the V-axis. After eliminating the effect of perspective, more invariant information of the road traffic signs could be conducive for subsequent detection and recognition.

III. Pitch and Yaw angle calculation based on Vanishing Point

According to the principles of projection geometry, a group of parallel lines in real space will intersect at a point at infinity with the presence of perspective distortion, and the projection of the intersection on the imaging plane is known as vanishing point. When a group of parallel straight lines in the real world and the image plane are parallel, the vanishing point will locate at infinity of the image plane. But when they are not parallel, the vanishing point will locate at limited range of the image plane, even within the image area.

Common vanishing point detection algorithm includes three categories: vanishing point detection based on space conversion technology, which maps infinity reality position of the image plane to a limited area, and then uses the mapping relationship between the two space to detect the position of the vanishing point in the projection space; vanishing point detection based on intersection, which calculates the intersection of every two straight lines in the main image, and then clusters intersection to achieve vanishing point detection; vanishing point detection based on statistical estimates, which uses feature points to construct cost function to check the image vanishing points, or uses local image texture features information and edge information to achieve vanishing point detection by voting.

Moghadam *et al.* [9], [13] propose a novel methodology based on image texture analysis for the fast estimation of the vanishing point in challenging and unstructured roads. The key attributes of the methodology consist of the optimal local dominant orientation method that uses joint activities of only four Gabor filters to precisely estimate the local dominant orientation at each pixel location in the image plane, the weighting of each pixel based on its dominant orientation, and an adaptive distance-based voting scheme for the estimation of the vanishing point. Finally, the highest number of votes overall pixel coordinates are selected as the vanishing point.

Given an input frame I(p), Moghadam method first convolves it with 4 Gabor filters at each pixel location p(x,y), $\hat{I}_{\varphi_n} = I(p) \otimes g_{\varphi_n}$, where g_{φ_n} is Gabor kernels with $\varphi_n \in \{0, \pi/4, \pi/2, 3\pi/4\}$. Then the Gabor energy responses are calculated by

$$E_{\varphi_n}(p) = \sqrt{Re(\hat{I}_{\varphi_n}(p))^2 + Im(\hat{I}_{\varphi_n}(p))^2} \quad (5)$$

Finding the direction of resulting vectors by suppressing each Gabor energy response by its orthogonal oriented directions,

$$||S_{\varphi_{sn}}(p)|| = |||E_{\varphi_n}(p)|| - ||E_{\varphi_{n+\pi/2}}(p)|||, n = 1, 2 \quad (6)$$

$$\begin{cases}\varphi_{sn} = \varphi_n & \text{if}||E_{\varphi_n}(p)|| - ||E_{\varphi_n+\pi/2}(p)|| > 0 \\ \varphi_{sn} = \varphi_n + \frac{\pi}{2} & \text{if}||E_{\varphi_n}(p)|| - ||E_{\varphi_n+\pi/2}(p)|| < 0\end{cases} \quad (7)$$

and then the local dominant orientation at each pixel is estimated as follows,

$$\begin{cases}O(p) = O_x + jO_y = S_{\varphi_{s1}}(p) + S_{\varphi_{s2}}(p) \\ \hat{O}(p) = tan^{-1}\frac{O_y}{O_x}\end{cases} \quad (8)$$

By defining a ray r_p=(p,$\hat{O}$(p)) for each $\hat{O}$(p) and weight each $\hat{O}$(p) by its sine function sin($\hat{O}$(p)), it calculates the weight of each pixel on the ray r_p based on its Euclidean distance.

$$\begin{cases}Dist_{p_i}(x,y) = \exp(\frac{-\hat{d}^2}{D_d}), \hat{d} = \frac{d}{D_p} \\ d = \sqrt{(x-x_i)^2 + (y-y_i)^2}\end{cases} \quad (9)$$

Where D_p is the maximum possible distance between each dominant orientation location p(x,y) and the intersection point of its ray r_p with the image perimeters, $p_i(x_i, y_i)$ is a pixel on the ray r_p in the image. Finally, the voting image is calculated as

$$VP(x,y) = \sum_{(x,y)\in r_{p_i}} sin(\hat{O}(p_i)) \times Dist_{p_i}(x,y) \quad (10)$$

A pixel with maximum number of votes in the voting image $VP(x,y)$ is selected as the vanishing point location (X_{pos}, Y_{pos}) of each frame.

After installing camera, we can calculate the initial value of pitch angle θ (see Fig. 2 c)) and yaw angle γ (see Fig. 2 b)) by the camera calibration method. However, in practical scenarios, the pitch angle θ and yaw angle γ is changing with the moving of the car and the slope changing of the road, which takes more IPM errors with fixed camera correction parameters. If considering both the pitch angle of the camera inside the car θ_c, and the variations of the slope of the road ahead $\delta\theta$, it is possible to obtain a corrected pitch angle θ as $\theta = \theta_c + \delta\theta$. We assume $\delta\theta$ = 0 and γ= 0 when we calibrate camera parameters. When the slope of road is changed the $\delta\theta$ is no longer zero, it makes the inverse perspective mapping not complete or excessive (see Fig. 4 a)-d)). But with the moving of the car mounted with camera in the real scenarios, when the optical axis direction and the camera deflection occurs in the horizontal plane, the yaw angle γ is changed, it makes some more perspective deformation (see Fig. 4 e)-f)), it makes the main road direction not vertical in the "bird's eye view" image. It will make some IPM errors without calibration of these changed pitch and yaw angles.

As an important feature of the perspective projection image formed in the imaging plane, the vanishing point can provide a lot of configuration information and the direction information for the scene analysis. It also can estimate the value of the vertical pitch angle and horizontal yaw angle parameter for the inverse perspective mapping automatically. The location of vanishing point can be used for automatic calculation [1] of yaw angle θ and pitch angle γ, as shown in Equation (11).

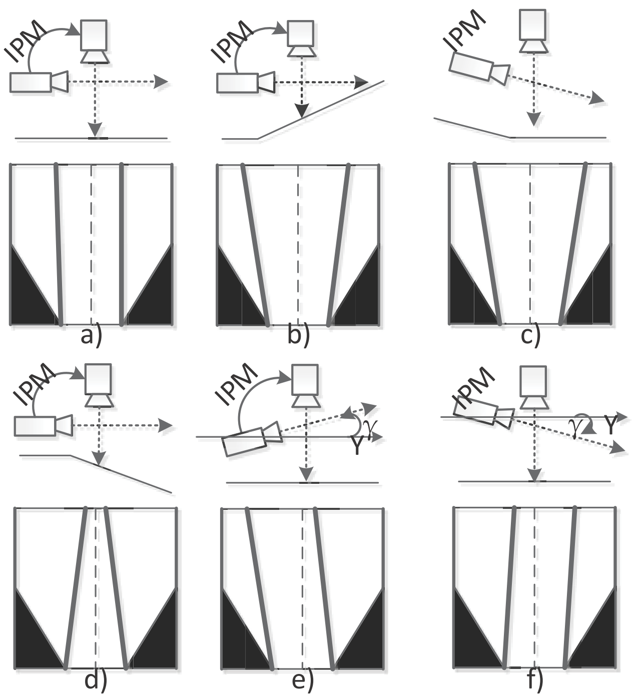


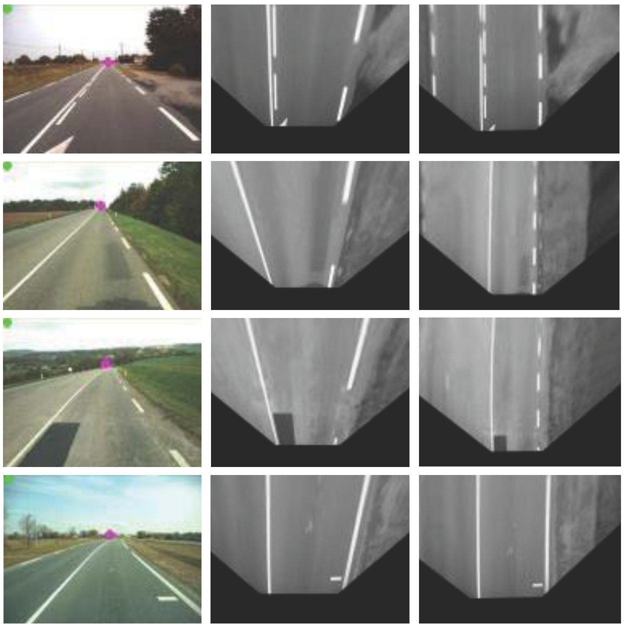
Fig. 4. Error caused by road slope variations and slight rotation, a)-d) shows effect of the road slope variations in the computed IPM images without pitch angle correction. e)-f) shows effect of slight rotation in the computed IPM images without yaw angle correction.

$$\begin{cases}\theta = \arctan(\tan(AlphaV) \times (1 - \frac{2Y_{pos}}{N})) \\ \gamma = \arctan(\tan(AlphaU) \times (\frac{2X_{pos}}{M} - 1))\end{cases} \quad (11)$$

Where (X_{pos},Y_{pos}) is the location of vanishing point in the image, (M, N) is the size of the image, $AlphaV$ and $AlphaU$ represent the camera angular aperture in the vertical and horizontal directions. Then we can calculate the pitch angle and yaw angle for each frame with the road slope changing and slight rotation of main road direction.

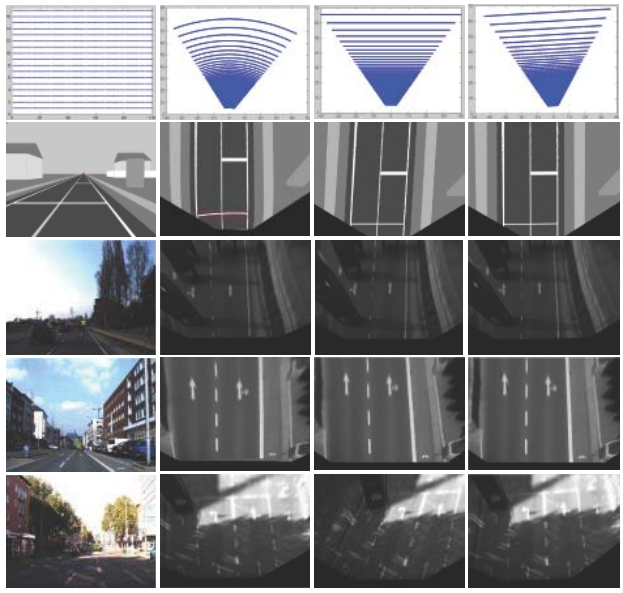
IV. Experiment

ROMA(ROad MArkings) [14] is a database of numerical images easily usable to evaluate in a systematic way the performance of road markings extraction algorithms. It comprises 107 original images of diverse road scenes, taken in a view point close to the one of the vehicles driver. Each original image comes with a reference image, build manually, which indicates the positions of the visible road markings. This ground truth can be used to test road markings extraction algorithms intensively and in an objective way. The calibration parameters of the camera is very useful for the processing of road markings, all images that share the same calibration parameters are grouped in a unique directory along with the calibration parameter file. The calibration parameters contains focal length F, the cell size (W,H), the translation (C_x, C_y, C_z) and the rotation angles (θ, γ, t_z) around X, Y and Z axis. All these parameters can be used for inverse perspective mapping for further road markings



a) Vanishing point　b) IPM Results based on fixed calibrated parameters　c) IPM Results based on Vanishing point

Fig. 5. Experimental results on ROMA database, first col is the original image with vanishing point detected by Moghadam method [9], the red cross is location of vanishing point, the second col is IPM results with the fixed calibrated camera parameters such as the pitch and yaw angle, the last col is IPM results based on vanishing point.



a) Vanishing point　b) Broggi　c) Eric　c) Proposed

Fig. 6. Comparison results of different inverse perspective mapping methods based on vanishing point. The first row shows the coordinate mapping relationship between different IPM method ,the second row to last one shows some image processing results in natural scene. The first col is the original image with vanishing point, the second col is IPM results by Broggi [11] method, the third col is IPM results by Eric [15] method, the fourth col is IPM results by the proposed method.

extraction. We compare the inverse perspective mapping result based on vanishing point [9] and the result with fixed calibration parameters contained in the ROMA database. The comparison results are shown in Fig. 5.

Fig. 5 shows that the adaptability of inverse perspective mapping based on the vanishing point detection method is superior to the existing methods with fixed calibrated parameters, which can provide more information for road sign detection and recognition. When faced with the uphill (the second row) and downhill road (the third row), our method can also get a good inverse perspective mapping result because it calculates the pitch and raw angle for each picture, but the inverse perspective mapping with fixed calibration parameters is not complete as the reason shows in Fig. 4 c) and d).

We then use cameras capture some highway images in different states, and a large collection of structured road pictures on the web with perspective effect, then they make up our experimental images database (including the actual shooting of 116 highway images and 51 network pictures). Fig. 6 shows some experimental results of our method that compare to some other IPM methods.

The first row in Fig. 6 reflect the coordinate correspondence between the world coordinate system and the image coordinate system, wherein the first column indicates the coordinates of the image coordinate system, the second column to the fourth column denote the word coordinate system processed by Broggi [11] method, Eric [15] and the proposed method. As can be seen, our method eliminates the ”horizontal line bending” phenomenon in [11], and also compensate the yaw angle and eliminates the slight rotation of the main road direction. The second row and second column shows the processing result by Broggi method has a ”horizontal line bending” phenomenon (curved horizontal line in the red box), which is not conducive to road signs detection and recognition that has a similar characteristics such as stop line; the second row and third column shows Eric method’s results without ”horizontal line bending” phenomenon, but the main road direction still has a slight rotation; the second row and the fourth column shows the results of proposed method that has calibrated these two errors, there is no curved horizontal line and the main road direction is nearly parallel with the V-axis in the world coordinate systems.

From the third row to the last row in Fig. 6 shows the compare results in the complex structure of the urban environment. Inverse perspective mapping can make the road signs become clearer (indicator arrow in the the third and fourth row). It can recover priori knowledge of the road plane itself that makes road signs detection more efficient, such as lanes are generally parallel to each other (the fourth row), stop line and the main road direction is vertical (fifth row). But when this inverse perspective mapping method is used to recover the non-planar objects above the road, there are significant distortions (such as the vehicles in the third and fifth row).

Common road signs such as lane, crosswalks and indicator arrows provide important road environment information. As can be seen from the experiments, the result "bird's eye view" image brings more priori knowledge for the detection of these road signs: lanes are generally white and yellow, the lane in a very short distance is parallel, and its main direction and the image coordinate system U-axis are almost perpendicular; stop line color is white, its direction and the image coordinate system U-axis is parallel. These prior knowledge can improve the accuracy and reliability of road signs detection and recognition.

V. CONCLUSIONS

This paper presents a automatic inverse perspective mapping method based on vanishing point detection for each frame that can eliminate the influence of slight rotation caused by yaw angle and perspective effect brought by the pitch angle. It detects the vanishing point location at first, then calculates the pitch and yaw angles based on the vanishing point and finally adopts inverse perspective mapping method to map the image from the image coordinate system to the world coordinate system to form a "bird's eye view" of the road plane. Experiments show that this method is more adaptable for the uneven road with different slope, which can get more invariant information of the road traffic signs and contribute to road traffic signs detection and recognition. This approach can also be applied to network images with unknown camera parameters to eliminate perspective effect automatically. However, vanishing point detection and the inverse perspective mapping process for each frame results in a high computational complexity, which is to be further optimized.

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