Accurate Distance Estimation Using Camera Orientation Compensation Technique for Vehicle Driver Assistance System

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Abstract—This paper proposes a camera orientation compensation technique to help compensating unwanted camera orientation so as to accurately estimate the distance of a preceding vehicle in a vehicle driver assistance system. We propose a method in computing a homography to compensate the unwanted camera orientation misalignment. Distance between the preceding vehicle and the digital camera can then be accurately estimated. We will demonstrate that this approach be most suitable for vehicle driver assistance systems, and it also further expands the extent of automobile safety.

Index Terms—Distance estimation, homography, vehicle driver assistance system, vanishing point, vehicle safety.

I. INTRODUCTION

In this work, we built a vehicle driver assistance system[1] to gives warnings to the driver when the host vehicle is about to collide with the preceding vehicle. To fulfill this task, we need a camera mounted inside the host vehicle, with (i) a vehicle recognition system and (ii) a vanishing point recognition system. First, the vehicle recognition system searches for the preceding vehicles and draws a bounding box circumscribing each detected vehicle. Second, the vanishing point recognition system recognizes the lane and computes the vanishing point[2,3].

Figure 1. A detected preceding vehicle and a computed vanishing point

Figure 2. Distance estimation for the ideal case: the optical axis is parallel to the Z axis.

Subsequently, we sample the coordinates of a point (Point P) on the bottom line of the bounding box and compute the distance of the preceding vehicle from the camera optical center, Z . For the ideal case, we have the optical axis of the

camera parallel to the Z axis, which is parallel to the road surface, as shown in Figure 2.

By means of camera calibration[4], we can compute the values of the camera height from the ground, H_c , in meter and the focal length, f , in pixel. The distance of the preceding vehicle, Z , can then be computed using the following equation.

$$Z = f H_c / y \quad (1)$$

where the coordinates of the point P is (x, y) with the image center being the origin of the coordinate system.

However, in practical case, the optical axis of the camera is not aligned with the Z axis as shown in Figure 3. We assume the camera is rotated about the X and Y axes by a small angle θ and ψ respectively. Therefore, distance estimation using (1) is no longer accurate. In this paper, we propose a method in computing a homography $\mathbf{H}$ which is capable of transforming point Q, in Figure 3, to point P, in Figure 2. The homography $\mathbf{H}$ essentially compensates the influence of the camera panning and tilting angles and simulates the situation as in the ideal case.

Figure 3. Distance estimation for practical case: the optical axis is not parallel to the Z axis.

II. PROPOSED METHOD

A. Model of the homography $\mathbf{H}$

Note that in this application, the geometric relationship between points P and Q is a pure camera rotation motion about the optical center. For this scenario, it can be shown that the homography $\mathbf{H}$ can be expressed in the following form:

$$\begin{pmatrix} lx \\ ly \\ l \end{pmatrix} = \mathbf{H} \begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} = \begin{pmatrix} r_{11} & r_{12} & fr_{13} \\ r_{21} & r_{22} & fr_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \begin{pmatrix} x' \\ y' \\ 1 \end{pmatrix} \quad (2)$$

where the coordinates of point Q is (x', y') , $\{r_{ij}\} = \mathbf{R}$ is a rotation matrix and l is a scalar of any value except 0. By means of camera calibration, we have the value of f . In this task, we need to estimate $\mathbf{R}$. Using the Rodrigues' identity, we can express the rotation matrix $\mathbf{R}$ as follows:

$$\mathbf{R} = e^{\alpha \mathbf{N}} = \mathbf{I} + \mathbf{N} \sin \alpha + \mathbf{N}^2 (1 - \cos \alpha) \quad (3)$$

where $\alpha = \|\Omega\|$, $\Omega = (\theta, \psi, 0)$, $\mathbf{n}=(n_x, n_y, n_z)=\Omega/\alpha$, and

$$\mathbf{N} = \begin{pmatrix} 0 & -n_z & n_y \\ n_z & 0 & -n_x \\ -n_y & n_x & 0 \end{pmatrix}$$

Since the angular magnitudes θ and ψ are small, we can approximate $\mathbf{R}$ as

$$\mathbf{R} \approx \mathbf{I} + \begin{pmatrix} 0 & 0 & \psi \\ 0 & 0 & -\theta \\ -\psi & \theta & 0 \end{pmatrix} = \begin{pmatrix} 1 & 0 & \psi \\ 0 & 1 & -\theta \\ -\psi & \theta & 1 \end{pmatrix} \quad (4)$$

Therefore, $\mathbf{H}$ becomes

$$\mathbf{H} = \begin{pmatrix} 1 & 0 & f\psi \\ 0 & 1 & -f\theta \\ -\psi/f & \theta/f & 1 \end{pmatrix} \quad (5)$$

B. Computation of $\mathbf{H}$

To compute the matrix $\mathbf{H}$, we need to compute the value of θ and ψ . We know that in the non ideal case, the vanishing point is not found at the image center while it is true for the ideal case. (See Figure 2 and 3) Since the origin of the image plane is the image center, mapping the vanishing point in Figure 3 using $\mathbf{H}$ must give us a zero vector. Therefore, we have

$$0 = x_v + f\psi \quad \text{and} \quad 0 = y_v - f\theta$$

where (x_v, y_v) is the coordinates of the vanishing point in the practical case (See Figure 3). Thus,

$$\psi = -x_v / f \quad \text{and} \quad \theta = y_v / f \quad (6)$$

Finally, we use equation (3) to calculate the matrix $\mathbf{R}$ and form the matrix $\mathbf{H}$ using equation (2).

C. Estimation of the preceding vehicle distance

In practical situation, the moving host vehicle vibrates and the vanishing point changes from time to time. Therefore, we need to constantly update the position of the vanishing point and update the homography $\mathbf{H}$. To estimate the distance of the preceding vehicle, we sample the coordinates of point Q and map it using equation (2) to get the equivalent coordinates of point P. Finally, we use equation (1) to compute the value Z.

Figure 4. Our vehicle driver assistance system: A bounding box circumscribes the detected preceding vehicle and the estimated distance from the host vehicle is 35.5 meters.

III. EXPERIMENTAL RESULTS

In this research, we developed a vehicle driver assistance system to warn the driver if the host vehicle is predicted to collide with the preceding vehicle within 2 seconds. We use the proposed technique to compensate the pan and tilt angles of the camera so as to give a much more accurate distance

estimate. We need to constantly update the position of the vanishing point to update the mapping homography $\mathbf{H}$. The following diagram shows the estimated distances with and without vanishing point (denoted as VP) updating compared with the RADAR distance estimates.

Figure 5. Estimated distances with and without vanishing point (VP) updating compared with the RADAR estimates. With vanishing point updating feature, the homography $\mathbf{H}$ can be updated constantly resulting much better distance estimates.

For the case without vanishing point update, we get the vanishing point coordinates by means of the camera calibration procedures. As the host vehicle moves, the vanishing point position changes as the camera orientation changes resulted from the vehicle vibration. Therefore, the homography $\mathbf{H}$ computed is not accurate. However, with vanishing point updating system, a reliable homography $\mathbf{H}$ is computed and we can accurately compensate the camera's pan and tilt angles using our proposed method giving a much more accurate distance estimation compared with the RADAR estimates. This distance measure has also been used for building our module for collision avoidance in our driver assistant system.

IV. CONCLUSION

We propose a method in estimating a homography $\mathbf{H}$ which is capable of compensating the camera pan and tilt angles. Experimental results showed that this can substantially increase the accuracy in estimating the preceding vehicle distance and boost the extent of safety in driving. Note that with vanishing point updating, our method can also estimate distances accurately for non-planar road surface scenario.

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