Ego-motion Computing for Vehicle Velocity Estimation

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Abstract. In this paper, we present a method for computing velocity using a single camera onboard a road vehicle, i.e. an automobile. The use of computer vision provides a reliable method to measure vehicle velocity based on ego-motion computation. By doing so, cumulative errors inherent to odometry-based systems can be reduced to some extent. Road lane markings are the basic features used by the algorithm. They are detected in the image plane and grouped in couples in order to provide geometrically constrained vectors that make viable the computation of vehicle motion in a sequence of images. The applications of this method can be mainly found in the domains of Robotics and Intelligent Vehicles.

Keywords: Vision, Ego-motion, Velocity Estimation, Intelligent Vehicles.

1 Introduction

Accurate estimation of the vehicle ego-motion with regard to the road is a key element for computer vision-based assisted driving systems. In this method, we propose the use of a single camera onboard a road vehicle in order to provide an estimation of its longitudinal velocity by computational means. The main advantage derived from the use of computer vision for ego-motion computation is the fact that vision is not subject to slippery, contrary to odometry-based systems. We propose to obtain couples of road features, mainly composed of road markings, as the main source of information for computing vehicle ego-motion. Additionally, the use of lane markings allows avoiding the use of complex direct methods [1], [2], [3] for motion estimation. Instead, motion stereo techniques are considered. This technique has previously been deployed in the field of indoor robotics [4]. The method is based on sampling a dynamic scene rapidly (e.g., 25 images per second) and measuring the displacements of features relative to each other in the image sequence.

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2 System Description

In outdoor scenes where many artificial objects and structures exist, a couple of static points that belong to the same object and are equally distant from the image plane may be observed and measured simultaneously. In particular, the left and right edges of lane markings constitute a clear example of coupled points that can be used for computing vehicle ego-motion using perspective projection laws. Let us, then, assume that there are two road points, P_1 and P_2, with coordinates (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2), where Z stands for the point depth (distance from the image plane). Let us assume that $Z_1=Z_2=Z$, which means that both points are equally distant from the image plane. The coordinates of the points in the image plane, p_1 and p_2, can then be computed as

$$\begin{aligned} p_1 &= \left(u_c + f_u \cdot \frac{X_1}{Z}, v_c + f_v \cdot \frac{Y_1}{Z} \right) \\ p_2 &= \left(u_c + f_u \cdot \frac{X_2}{Z}, v_c + f_v \cdot \frac{Y_2}{Z} \right) \end{aligned} \tag{1}$$

where u_c and v_c represent the coordinates of the principal point in the image plane (optical center), and f_u and f_v are the camera focal length, given in pixels units, in the u (horizontal) and v (vertical) axes, respectively. Let $B=|X_1-X_2|$ be the horizontal distance between the road points and $b=|x_1-x_2|$ the horizontal distance between the corresponding image points. Based on the previous statement, $b=f_u \cdot B/Z$. Finally, let us consider that the camera is translated causing the two road points to move relative to the camera with the velocity $(dX/dt, dY/dt, dZ/dt)$ while f_u and B remain constant. In general, the derivative of b with respect to time can be computed as

$$\frac{db}{dt} = \frac{db}{dZ} \cdot \frac{dZ}{dt} = -\frac{f_u B}{Z^2} \cdot \frac{dZ}{dt} = -\frac{b}{Z} \cdot \frac{dZ}{dt} \tag{2}$$

For a couple of road points, the distance from the image plane Z can be computed under the planar road assumption as follows

$$\begin{aligned} \theta &= \tan^{-1}\left(\frac{H}{Z}\right) \\ v &= f_v \cdot \tan(\theta - \alpha) \end{aligned} \tag{3}$$

where Ɐ stands for the camera pitch angle with respect to the horizontal line parallel to the road, v is the vertical coordinate of the coupled road points in the image plane, and H is the camera height with respect to the road plane. Let us remark that coordinate v can be directly measured from the image, while parameters H and Ɐ are supposed to be known.

Based on relations (2) and (3), an equation can be formulated for each couple i of road points equally distant from the image plane. Equation (4) shows a mathematical relation from which vehicle velocity $(v=dZ/dt)$ can be computed.

$$v=\frac{dZ}{dt}=-\frac{Z_i}{b_i}\cdot\frac{db_i}{dt} \tag{4}$$

Let N_t represent the number of road point couples found by the algorithm at frame t. The optimal estimation of vehicle velocity v can be done by optimizing the system formed by the N_t equations that can be written at each iteration of the algorithm. Based on the previous statement, the problem can be mathematically formulated as the minimization of the estimation square error SE, represented in equation 5.

$$SE=\frac{1}{N_t}\cdot\sum_{i=1}^{N_t}\left(\hat{b}_i-b_{i,t}\right)^2 \tag{5}$$

where $\hat{b}_i$ represents the estimation of b for couple i, and $b_{i,t}$ stands for the measurement of b for couple i at frame t. This criteria leads to the final value provided in equation (6).

$$v_t\approx\frac{\sum_{i=1}^{N_t}\left(\frac{db_{i,t}}{dt}\right)\cdot\frac{b_{i,t-1}}{Z_{i,t-1}}}{\sum_{i=1}^{N_t}\left(\frac{b_{i,t-1}}{Z_{i,t-1}}\right)^2} \tag{6}$$

where $b_{i,t-1}$ represents the measurement of b for couple i at frame $t-1$, and $Z_{i,t-1}$ stands for the depth measurement for couple i at frame $t-1$.

3 Implementation and Results

The algorithm was implemented on a PC onboard a real automobile in a test circuit. A Firewire camera was mounted on the test car, providing 640x480 Black&White images in IEEE 1394 format. The couples of road points detected by the algorithm in a real experiment are depicted in green on the left hand side of Figure 1. It must be remarked that the correspondence of road points between two consecutive images is carried out by implementing an optical flow. In the same figure, the instantaneous estimation of vehicle velocity at the current frame is provided (37.24 km/h), as well as the accumulated length of the path run by the car (292.78m in this example). Similarly, the estimation of vehicle velocity is provided in the right hand side of Figure 1 for the complete duration of the experiment. The vertical axis represents

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vehicle velocity in km/h. The red curve depicts vehicle velocity estimation without filtering, while the blue curve depicts vehicle velocity estimation using a kalman filter. The final result issued by the algorithm demonstrated to be very similar to the vehicle velocity measured by odometry means (around 40 km/h).

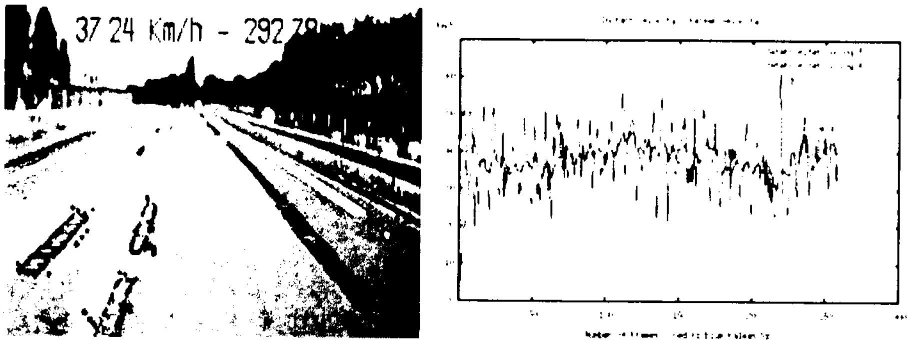

Fig. 1. Detection of coupled road points (left); velocity estimation using vision (right).

At present, the estimation of vehicle velocity is being used in the prediction stage of kalman filtering in Lane Departure Warning (LDW) Systems developed by the authors. Similarly, the estimation of vehicle ego-motion is currently being extended to a 6-component vector providing the complete ego-motion information, including vehicle longitudinal and angular displacement in *X*, *Y*, and *Z*.

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