# The use of optical flow for the autonomous navigation

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**Abstract.** This paper describes the analysis of image sequences taken by a T.V. camera mounted on a car moving in usual outdoor sceneries. Because of the presence of shocks and vibrations during the image acquisition, the numerical computation of temporal derivatives is very noisy and therefore differential techniques to compute the optical flow do not provide adequate results. By using correlation based techniques and by correcting the optical flows for shocks and vibrations, it is possible to obtain useful sequences of optical flows. From these optical flows it is possible to estimate the egomotion and to obtain information on the absolute velocity, angular velocity and radius of curvature of the moving vehicle. These results suggest that the optical flow can be successfully used by a vision system for assisting a driver in a vehicle moving in usual outdoor streets and motorways.

## 1 Introduction

There is now a good understanding of the optical flow and it is useful to evaluate the possibility of computing and using the optical flow obtained from image sequences taken by a camera mounted on a vehicle moving in a city center and in the countryside.

This paper is primarily devoted to the analysis of such image sequences. It will be shown that it is possible to recover an adequate optical flow (Horn & Schunck, 1981; Nagel, 1983; Verri, Girosi & Torre, 1990) on selected areas of the image and to obtain a reasonable estimate of the absolute velocity, angular velocity and radius of curvature of the trajectory of the moving vehicle.

## 2 A comparison

When the vehicle moves on a flat road (see Fig. 1A) the expected motion field is characterized by a divergent flow. Panels B, C and D of Fig. 1 illustrate a comparison between three techniques for computing the optical flow from the image sequence of which one frame is shown in Fig 1A. The optical flow computed with the technique of Uras et al. (1993) (B) has large areas with no vectors. The optical flow (C) computed with the technique of Campani & Verri (1990) is blurred. The optical flow computed with a correlation based technique is clearly superior

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(D). It is evident that differential techniques (see B and C)do not provide an optical flow which is similar to the expected motion field. The results of this comparison were confirmed by the analysis of at least 15 image sequences: consistently differential techniques provided poor results. In previous comparisons differential techniques did not perform badly, because the viewing camera was fixed or carefully displaced (De Micheli, Uras & Torre 1993) . On the contrary in image sequences analysed in this paper, shocks and vibrations introduced a high frequency noise which was greatly amplified during the computation of temporal derivatives. As a consequence differential techniques were intrinsically noisy and failed to provide useful optical flows. Correlation techniques, by construction, do not compute temporal derivatives and therefore do not amplify the noise.

## 3 The 2D motion field

When the vehicle moves on a flat road and the vehicle translation $\mathbf{V} = (V_i, 0, 0)$ is parallel to the optical axis of the viewing camera, it is convenient to model the 2D motion field $\mathbf{v} = (v_x, v_y)$ as

$$v_x = \frac{\omega}{f}x^2 + \frac{V_i}{hf}xy + \omega f \qquad (1)$$

$$v_y = \frac{\omega}{f}xy + \frac{V_i}{hf}y^2 \qquad (2)$$

where $f$ is the focal length of the viewing camera, $h$ its height from the ground, $\omega$ the angular velocity and $x, y$ are coordinates on the image plane. This 2D motion field is a correct model of the motion field when the vehicle moves on a flat road over a flat landscape and is also an approximation of the motion field at the two sides of the road in the absence of other moving vehicles or objects. As a consequence eqns (1–2) are assumed to represent the structure of the expected motion field in the case of passive navigation in a fixed scenario. As the focal length $f$ is assumed to be known, the expected motion field depends on the two quantities: $\omega$ the angular velocity and the instantaneous velocity $V_i$. These two quantities are easily related to the instantaneous radius of curvature $\rho$ by $V_i = \omega\rho$. The real 2D motion field of passive navigation is the sum of the 2D motion field caused by the egomotion and the 2D motion field produced by shocks and vibrations $\mathbf{s} = (s_x, s_y)$ experienced by the T.V. camera. The image sequences analysed in this paper were obtained with a T.V. camera mounted on a high quality antivibrating platform, but nevertheless the motion field $\mathbf{s}$ is not negligible.

## 4 The recovery of egomotion

The estimation of egomotion is obtained in two steps: first optical flows are computed and corrected for shocks and vibrations and then motion parameters are

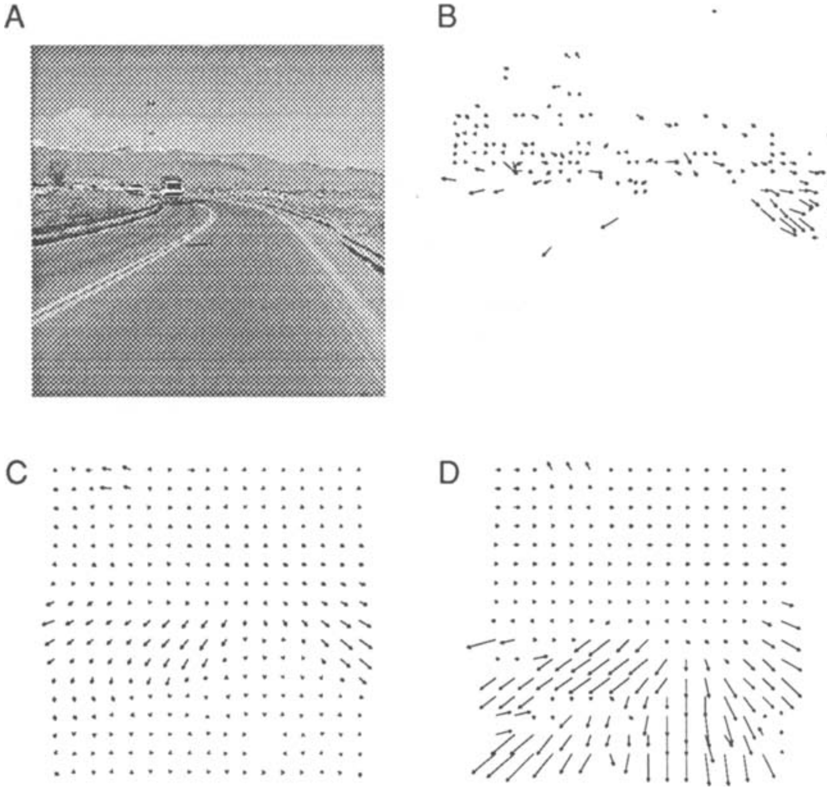

**Fig. 1.** Comparison of optical flows computed with different procedures. A: a frame of the image sequence. B: optical flow computed with the technique of De Micheli et al., 1993. C: optical flow computed with the technique of Campani & Verri, 1992. D: optical flow computed with a correlation based technique.

recovered from corrected optical flows. Fig 2A and B reproduce optical flows obtained when the vehicle was moving along a straight road or along a curving road respectively. These optical flows show random upwards and downwards global deflections caused by vibrations and shocks. In the case of passive navigation and if the optical axis is parallel to the ground, the optical flow around the horizon, assumed to be located in the image plane near the line $y = 0$, is expected to have a vertical component equal to zero. Therefore it is possible to assume as an estimate of $s_y$ the average vertical displacement $< s_y >$ in the strip between the two lines $y = -c$ and $x_2 = c$. As a consequence a possible correction for shocks and vibrations can be obtained by computing in each flow the value $< s_y >$ and then subtracting $< s_y >$ from the original flows. In these image sequences the value $< s_x >$ was significantly smaller than $< s_y >$ and no correction for horizontal shocks was necessary. The corrected optical flows are shown in C and D. These corrected optical flows have the expected qualitative

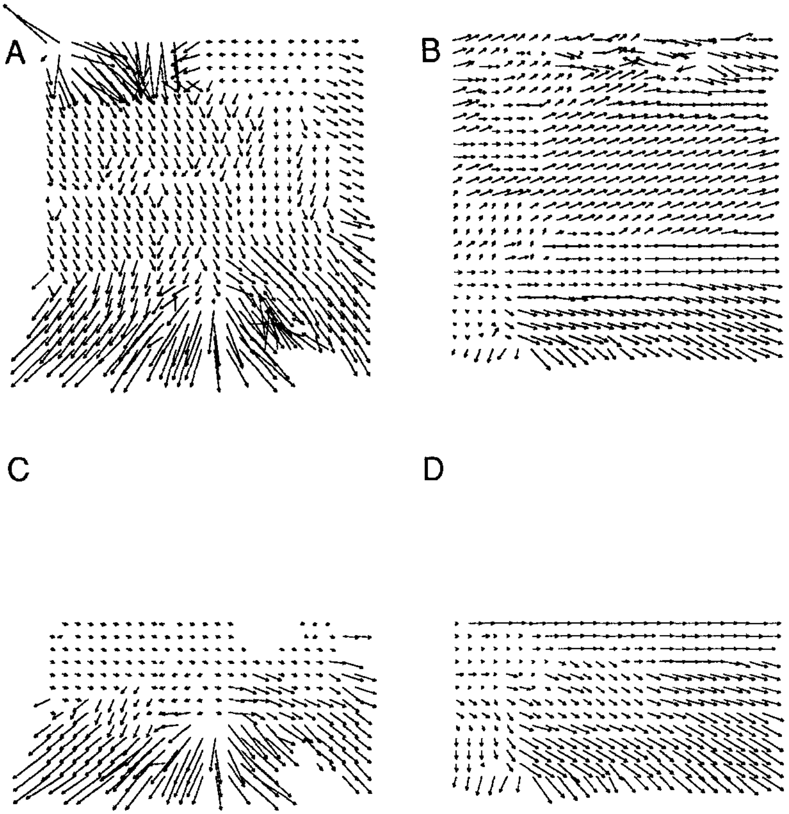

**Fig. 2.** Optical flows computed with a correlation technique from an image sequence taken while the vehicle was moving in a rectilinear way (A) and was moving in a curvilinear way (B). The corrected optical flows are shown in C and D.

behaviour and are shown only in the lower part of the image, where the flow is significant and reliable. Given the model of egomotion represented by eqns. 1–2, the recovery of egomotion implies the estimation of the two parameters $\omega$ and $V_i$. We have analysed three different methods, the first to be used only in the case of rectilinear motion (Method 1) and the other two (Method 2 and 3) for the general case. Method 1 assumes that the vehicle is moving by a pure translation so that the parameter $\omega$ is equal to 0 and it is necessary to estimate only $V_i$. This method provides better results with a double fit procedure: the corrected optical flow is fitted with eqns (1–2) and an estimate of $V_i$ is obtained; then all vectors which differ significantly from the values obtained from eqns (1–2) with $V_i$ equal to the first estimate are discarded and a second fit with eqns (1–2) of the remaining vectors is performed. Method 2 first estimates $\omega$ by computing the average horizontal displacement along the vertical axis $x = 0$. When this estimate of $\omega$ is obtained, $V_i$ is estimated in three regions roughly corresponding to the left, center and right of the lower parts of the image. The final estimate of $V_i$ is that obtained in the region with the smallest estimate variance. Method 3 estimates $\omega$ and $V_i$ simultaneously in the three regions (left, center and right) . As in Method 2 the final estimate is that obtained from the region with the smallest variance.

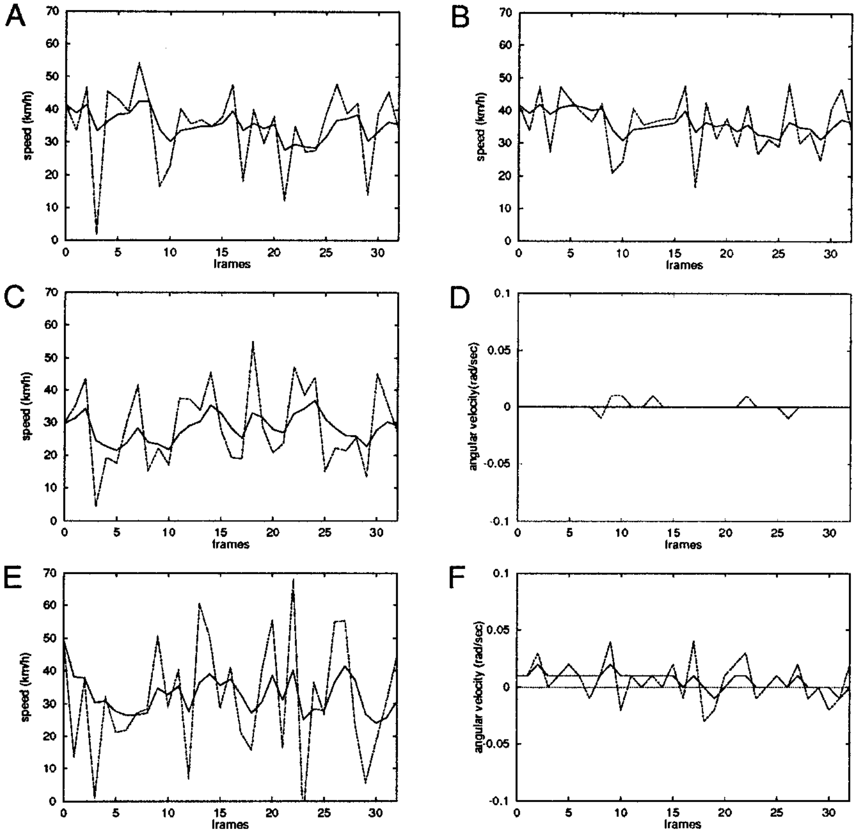

**Fig. 3.** Comparison between the three methods, illustrated in the text, to recover the egomotion parameters. Data shown in the first row were obtained with Method 1 after one fit (first column) and after two fits (second column). Data shown in the second and third row were obtained with Method 2 and 3 discussed in the text. The first column refers to the recovery of the instantaneous velocity $V$ and the second column to the recovery of the angular velocity $\omega$. The broken line is the instantaneous estimate and the broken line is the estimate obtained by a suitable Kalman filtering.

### 4.1 Comparison of the three methods

Fig 3 illustrates a comparison between the three Methods for the case of rectilinear motion. The first, second and third row corresponds to Method 1, 2 and

3 respectively. The angular velocity $\omega$ was estimated only from Method 2 and 3 ( see D and F ). The continuous lines indicate the raw estimate and the broken lines represent a smoothing after a Kalman filtering (see legend of Fig. 3). All three methods provide an average instantaneous velocity of about 35 Km/hr, which was consistent with the reading of on board instruments. Method 2 gave an average angular velocity around zero, while Method 3 gave an erroneous average angular velocity of about .01 rad/sec. In addition it is useful to observe that the raw estimates provided by Method 2 were usually more consistent than those obtained by Method 3 and the first fit of Method 1. A total of 25 image sequences were analysed and consistent results were usually obtained. The performances of Method 2 appeared to be slightly better than those of Method 3.

## 5 Discussion

The results presented in this paper show that it is possible to compute a useful optical flow from image sequences obtained with a T.V. camera mounted on a vehicle moving along usual outdoor environments: indeed it is possible to recover the egomotion and information on the presence of relative motion.

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