Qualitative Visual Navigation Using Weighted Correlation

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Abstract

Based on flat ground assumption, a correlation method is developed to estimate orientation of vehicle relative to its running environment. A weight function is introduced to account for figure variation caused by 3D dynamic scene and perspective effect caused by the camera system. The estimated parameters can be qualitatively used in visual navigation. Promising results indicate that robust estimation can be achieved in real time by using powerful image processing system PIPE(Pipelined Image Processing Engine).

1. Introduction

Autonomous visual navigation has been a challenging problem of image understanding for many years and several methodologies, such as image analysis based on image segmentation, image flow method and structure from motion, have usually been used to deal with such situations. However, though both image flow method and structure from motion continue to be the focus of research, the state of the art indicates that they have not matured to be used in sophisticated environment with real time requirement. Recently several methods have been suggested based on segmentation, in which road area is first delineated and then be analyzed so that useful information can be drawn for steering vehicle automatically. Being aware of the weakness of segmentation and the difficulties in analysis, we try to develop a novel method based on correlation in which no segmentation is prerequisite and the dynamic information appearing in image sequence can be used in a more effective and efficient way.

2. The Outline of Weighted Correlation Method

We use a robot centered coordinate system(xyz) and an image coordinate system(uv), shown in Fig. 1. "O" indicates the optical center.

Since roadway can usually be depicted by a planar model, motion of vehicle can be simplied to planar motion. For two images It and It+1 in a sequence, suppose that the motion of vehicle between these two images is $(\Delta x, \Delta z, \Delta\theta)$, where Δx and Δz are translation components, while $\Delta\theta$ is the rotation effect. Project It to xoz plane, then produce next view of It in xoz plane after motion $(\Delta x, \Delta z, \Delta\theta)$, finally reproject it back to uv plane, if we denote the resultant image as $I\acute{t}+1$, then the corresponding points on the roadway will coincide in It+1 and $I\acute{t}+1$. This transformation is based on flat ground assumption, therefore, the predicted view of the scene, $I\acute{t}+1$, is an approximation of the road scene, for that only the figures on the ground can be predicted exactly. In order that correlation results mainly reflect the situation in road area, a weight function is introduced to diminish the effect of inaccuracy caused by this approximation: If the difference of a pixel pair is not negligible, this pixel will be bypassed in correlation computation; This usually occurs in areas corresponding to objects with height, especially when the the objects are moving. If different possible motion parameters between It and It+1 are set, the one reflecting the real motion of vehicle will result in maximal similarity of It+1 and $I\acute{t}+1$.

The outline of weighted correlation method is as follows: the current image of the scene is squeezed and transformed into 64 low−resolution image of 32 * 32 with different possible motion parameters, the successive image is also squeezed to the same number of low−resolution images, but all of which are simply the squeezed version of the original one. These two image arrays are then correlated correspondingly, the pair with maximal correlation value is chosen as the most similar one and its preset parameter is used as estimation of motion of vehicle.

3. Visual Navigation Based on Weighted Correlation

3.1. Egomotion Estimation and Evaluation

The parameter set corresponding to maximal correlation value is usually explained as egomotion estimation. However, as the difference of scenes in image sequence may depend on many factors, the calculated results should be carefully analyzed , so that it can be used in a proper way.

First, if the vehicle is really running on a static environment, with features such as shadows etc. on the ground, or with the orientation of vehicle not parallel to the axis of roadway, the accuracy of egomotion estimation can be expected. However, some special cases need to be mentioned, for example, when the vehicle is running in the direction parallel to the boundary of straight equal−width road without any texture or object on it, the scene in the image sequence will not change at all, as a result, the egomotion can not be uniquely determined by our correlation method, just like "aperture problem" in computer vision literature.

3.2. Estimating Relation Between Vehicle and Its Environment

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It is realized that another more important issue for visual navigation is to estimate the orientation of vehicle relative to the roadway. If the direction of vehicle is quite different from direction of roadway, it should be detected out and rectified just in time. In order to sense this relative orientation, we develop a two–step method by using correlation. We use one example shown in Fig. 2 to explain it.

In Fig. 2(a), a straight road is concerned. For simplicity without losing the generality, the vehicle is supposed to be running in the z direction with a translation of Δz. In an equivalent way we can express the relative motion of road way by Fig. 2(b), in which a dashed line is used to show the relative movement of the road edge. As no end of the road appears in the image, the relative movement of roadway can be equivalently expressed by a pure translation δx along x direction. Since δx can also be determined with the correlation method by assuming that Δz is zero, the relative orientation $\delta\theta$ between vehicle and the straight road can be estimated by $\delta\theta = \mathrm{atan}(\delta x / \Delta z)$.

This technique can be extended to account for nonstraight road with complicated movement of vehicle, for details refer to [2].

Due to that Δz component of egomotion estimation may not be determined properly in some situations mentioned earlier, we prefer to use a rough estimation of Δz based on the estimated velocity of running vehicle. In fact, δx itself can be used instead of $\delta\theta$ to estimate relative orientation of vehicle if qualitative principle[1] is used in visual navigation.

4. Results and Conclusions

The weighted correlation method is implemented on PIPE system[3], 64 results of weighted correlation corresponding to 8 * 8 image pairs of size 32 * 32 can be provided in 3 / 60 s. In our experiments, the running speed of vehicle is about 5km / h. Fig. 3 and Fig. 4 show experimental results of calculated $\Delta\theta$ and δx, we can see that both of them are reliable.

The main advantages of this method can be summarized as follows:

(1) No prerequisite of image segmentation.

(2) Orientation based on dynamic information.

It is realized that in ideal situations, such as static environment with regular road model, orientation of vehicle can be estimated quite well by means of many methods, such as moment calculation. In the complicated and dynamic situation, however, the performance of such method will drop off drastically. On the contrary, in our method each image is analyzed in conjunction with its successor, and the effect of moving objects on roadway can be diminished quite well, so its robustness can be expected and has been proved in our experiments.

(3) This method can be adapted to speed variation of vehicle by changing the sampling rate according to rough speed estimation.

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[3] Programming PIPE Model 1 Systems, Aspex Incorporated.

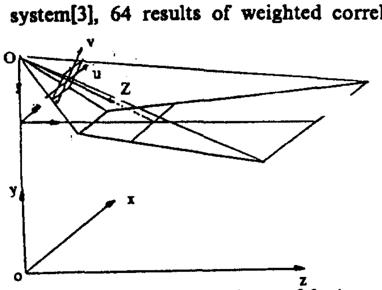

Fig. 1. Coordinate Systems for Planar Motion.

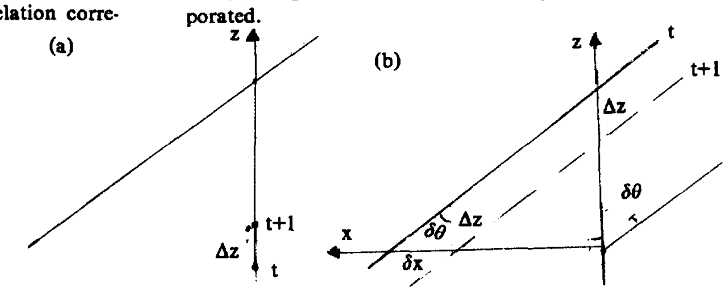

Fig. 2. Calculation of Equivalent δx and $\delta\theta$ in Straight Path.

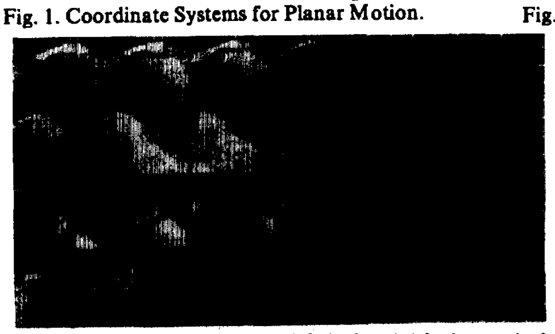

Fig. 3. Experimental Results of Calculated $\Delta\theta$: the vertical and horizontal axes indicate time t and rotation $\Delta\theta$ respectively.

Fig. 4. Experimental Results of Calculated $\Delta\theta$ and δx: the left curve and the right curve represent $\Delta\theta$ and δx respectively.