ROAD FOLLOWING ALGORITHM USING A PANNED PLAN-VIEW TRANSFORMATION

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1 Introduction

Driving a robot vehicle along a road using computer vision is a goal that is receiving attention worldwide from many research groups [1–5]. The purpose of the work is to interpret the image sensed by the vehicle in order to drive safely along a road. The major components of an autonomous vehicle consist of perception, reasoning, path planning and vehicle control.

Bristol University has been funded since 1986 to investigate the main components of these tasks and to work on a computer hardware architecture capable of performing the various tasks concerned. A Real-Time Image Processing System based on Inmos transputers has been developed and built. A small tracked vehicle has been used to test in a real environment the algorithms proposed. The first outdoor experiments were performed in December 1988 in which the vehicle followed part of a gravel path in the University gardens. This work is concerned with the vision perception and the reasoning task using temporal and spatial constraints to guide a robot vehicle along a road.

Two approaches for road segmentation have been described in the literature: pixel classification [1–3] and edge detection [4–6]. The technique presented here is a different approach to road segmentation. It is based on the observation that a road is a large homogeneous feature separated by parallel boundaries. Two parameters make the feature extraction difficult in typical road scenes: the perspective problem (making the edge detection fail) and the various possible inclinations of the road boundary line in the image (making shape recognition a more difficult task). The proposed method, first introduced in [7], consists of building a subsampled image using a *panned plan-view transformation* where the resultant image has the perspective view corrected, with all pixels representing the same spatial dimension in the world. The transformation has a pan angle which is adjusted to make the road edges vertical in the plan-view image. Assuming that the road has no sharp corners, a curved portion of the road can appear as two parallel circular arcs with predominantly vertical edges. The panned plan-view image is a powerful and compact representation of the road scene. It preserves all the main features to enable an accurate road boundary extraction. A typical compression factor is 32, reducing the raw image from 256 x 256 pixels to 64 x 32 in the panned plan-view image.

2 Vision System Architecture

Figure 1 shows a block diagram of the vision algorithm. The algorithm extracts the road boundaries and updates a road model to drive a vehicle along the road.

Once the monochrome image is digitised, the panned plan-view transformation is applied, resulting in a spatially reduced subsampled image representing a portion of the view in front of the vehicle. This image is used to extract the road boundaries using a large vertical edge detecting operator. The size of the operator has been chosen based on the fact that the road represents a large predominant feature in the image. A thinning and linking edge procedure filters the edges into a list of edge segments. These linked edge points are then transformed from the plan-view image coordinate system to the vehicle coordinate system. A straight line fitting algorithm converts the edge segments into a list of line segments. Then, the reasoning module makes use of geometric and temporal constraints to classify the segments lines into left, right or non-road edge segments. The classification criteria are based on the previous road reference and on the assumption that the road consists of parallel boundaries with only a small variation in width from cycle to cycle. Finally, the new road reference is updated and a predicted pan angle is determined for use in the plan-view transformation in the next cycle. The reasoning system is designed to cope with situations in which only one side of the

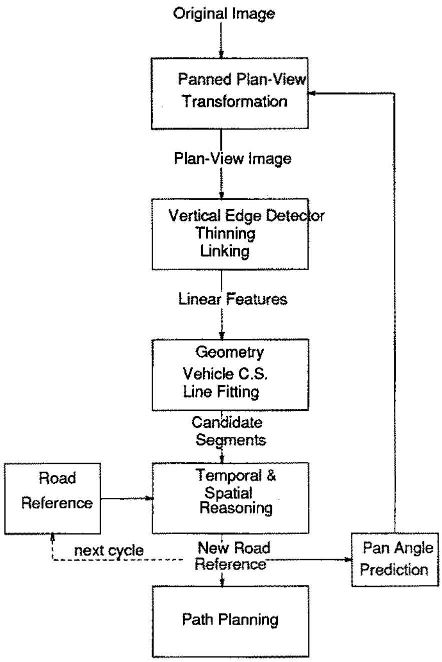

Figure 1: The vision algorithm

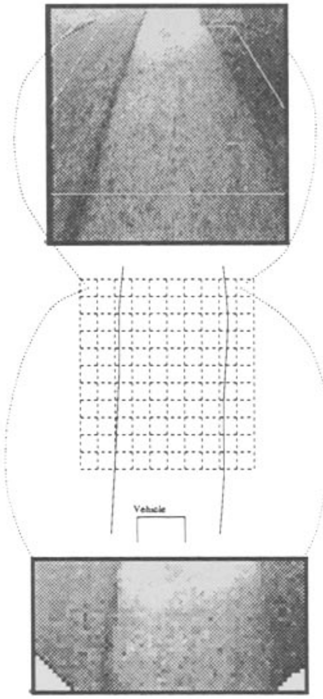

Figure 2: The panned plan-view image

road is visible. It keeps tracking the single road edge seeking for the other side to reappear using the information of the last road width extracted.

3 Panned Plan-View Transformation

The proposed method consists of selecting a rectangular area in front of the vehicle where a perspective transformation is applied. The position of the area is specified by the pan angle parameter. It orients the rectangular area to include the road edges in situations where the road is not straight. For each road image there is a pan angle which enables the road edges to appear as near-vertical parallel features. The transformation is applied to a number of equally spaced points in the selected area, reducing the amount of pixel data to be processed in the road feature extraction. The data reduction and the fact that the road always appears with approximately the same shape makes the method robust, relieving later algorithms from dealing with too much unstructured data. The pan angle is predicted by determining the angle between the central axis of the road and the vehicle trajectory. This method compresses the raw image while preserving all the main road features of interest. The panned plan-view image has each pixel representing a uniform area in the road plane and the road edges are represented as vertical or nearly vertical features.

Generating a panned plan-view image

The panned plan-view image of the road is generated by applying the transformation on a rectangular regular grid of points over the road plane. The plan-view transformation uses the assumption that the road is locally flat and all road features belong to the road plane. Although this requires a locally plane terrain, the method can cope with hills and valleys with small slopes.

Figure 2 illustrates the process of building the panned plan-view image. The top of Fig 2 shows the grid boundary used in the transformation superimposed on the original image. The centre of Figure 2 shows a schematic view of the road in the vehicle coordinate system and the bottom of

Fig 2 shows the resultant panned plan-view image. Its dimensions are 64 by 32 pixels, reducing the raw image data of 256 x 256 pixels by a factor of 32. The lateral dimension of the image is greater than the longitudinal direction giving a higher resolution laterally in order to make the extraction of the road edges more accurate.The pan angle θ performs an important part in ensuring that a useful panned plan-view image is generated with the road edges predominantly vertical. The choice of the pan angle is done automatically by the reasoning module after it has built the road model. The pan angle is determined by measuring the angle between the central axis of the road and the vehicle's direction of the motion.

Noise in subsampling

The reduced panned plan-image is generated by subsampling the individual pixels specified by the transformation without any previous smoothing so the resultant image is slightly noisy. To study the effect of this noise on the edge detector operator applied later, two methods of smoothing the original image are compared to the unfiltered method described.

The results of the edge detector operator applied to a non-smoothed, a gaussian smoothed and a pixel averaging smoothed images were compared visually.Although the gaussian smoothing has shown the best noise figure of the three methods, the unfiltered image is used to achieve real-time processing since the degradation effect of its edge detector output is comparatively small.

4 Road Edge Detection

The road edge extraction algorithm consists of two modules: feature extraction and geometric modules. The Feature Extraction module is responsible for detection of the candidate road features in the panned plan-view image. The output of the feature analysis is sent to the geometric module which transforms those features from the plan-view image pixel coordinates into the vehicle coordinate system, converting them into a sequence of straight line segments.

Feature Extraction

The process of extracting road edges from the plan-view road image involves several steps: applying a vertical convolution mask, thresholding and thinning the edges and finally linking. All the above algorithms assume that the road in the plan-view image is a large predominant feature with boundaries edges nearly vertical. This assumption makes it possible to improve the algorithms to extract the road edges.

A vertical gradient edge detector followed by a non-maxima suppression thinning technique is used to detect the predominantly vertical edges.

Linking edges can be a complex task when the image contains edges in all directions. In this case the task of linking segments is easier as the edges are near vertical and are well separated. The search process looks for its successor cell amongst the five neighbouring cells in the row below. If more than one is found, the nearest edge is chosen. The output of the linking algorithm is a list of edge segments in the panned plan-view image pixel coordinates.

Geometric module

The Geometric module receives as input a list of edge segments from the feature extraction module. The main steps performed by the geometric module are: translation from the panned plan-view image pixel coordinate system to the vehicle coordinate systems, linking possible gaps between segments, and application of a line fitting algorithm to those segments. The output of this module consists of a list of linked vector candidates on the right and the left road boundaries.

The line fitting uses the iterative endpoint fit algorithm. A list of curves approximated by straight lines is the output of the geometric module. The curves are candidates for right and left road boundaries.

5 Spatial and Temporal Reasoning

The reasoning module classifies each segment candidate for left and right road boundaries using spatial and temporal constraints. Normally, for an image with a well defined road with a discriminant background, the output of the geometric module consists of two road edges representing the road and the classification is trivial. In conditions where the feature extraction cannot cope with noise or imperfections on the road surface or when only one road edge is visible (a T junction or a sharp curve), or where the background is complex, the list of segments extracted may be fragmented or may not correspond directly to the left and right road edges.

The reasoning module uses both spatial and temporal constraints. The spatial constraints use the assumption that the road edges should be parallel segments separated by a predicted road width. The temporal constraints use a zeroth order prediction to match the best left and right segments against the previous road description. The zeroth order prediction is used since the vehicle used to test the algorithms has no sensors to feedback the actual movement displacements commanded. As the vehicle's maximum speed is about walking pace and the cycle processing time is just over two seconds, the road edges are within a reasonable distance to enable a correct matching correspondence. In the case where the vehicle moves at a faster speed, sensors would give important clues in predicting the road position. In this case it would be possible to take into account the vehicle movements and use a first order prediction.

There are two basic measures used in the reasoning module from which all other criteria are derived: The degree of overlap and the segment matching measures. The degree of overlap gives the amount of support the two segments exhibit in the horizontal direction. The segment matching measure gives the average distance and variation between two overlapping segments. A good road description consists of two segments with a large overlap, an average distance representing the road width and a small variation in the width reflecting the parallelism of road edges. A good correspondence matching requires a large overlap, a minimum width and a minimum width variation. The implementation details of these two measures are described later.

The algorithm uses a road reference data structure consisting of the right and the left road edge segments and the road width. The edge segments are linked lists of straight lines. The right or the left segment may be null if there is not enough evidence of its road segment pair.

6 Predicting the Pan Angle for The Panned Plan-View Transformation

The panned plan-view transformation requires the pan angle parameter to determine the correct rectangular grid. Properly selecting the grid ensures the road edges are strong vertical features in the plan-view image.

The pan angle used for the transformation is the angle that the axis of the movement of the vehicle makes with the central axis of the road at a fixed distance (D_n) ahead of the vehicle. The predicted pan angle is taken as weighted average of the inclination of both road segments from the new road reference extracted. The average is weighted by the length of each road segment. In the case of initialization or where no road edges are extracted, the current pan angle is set to zero, i.e. looking straight ahead of the vehicle.

7 Implementation and Tests

The algorithms have been implemented in Parallel C on a transputer based image processing system. The system has been developed and built at the University of Bristol as part of its Autonomously Guided Road Vehicle project. The basic system consists of a monochrome video A/D converter capturing 256 x 256 pixels of 8 bits in a non-interlaced standard TV 50 Hz format. The frame grabber is double-buffered and is located in the transputer address space. The frame can also be displayed, assisting the development of real-time image processing algorithms.

A small tracked battery operated vehicle is used for testing. The road used for testing is a gravel path in the University gardens. The road edges are sometimes ill defined. Grass and other vegetation defines the sides of the path. Simple algorithms based on pixel classification or simple edge detections were unable to properly segment the path. There are also circumstances where only one edge of the road is visible which constitutes a severe test for any road following algorithm.

8 Conclusions

We have presented a real-time vision system for vehicle road following using a panned plan-view transformation together with temporal and spatial reasoning. The panned plan-view transformation has proved to be a significant feature for improving both speed and robustness in the road feature extraction tasks. The road is seen as a large predominant feature in typical scenes. The panned plan-view transformation successfully compresses the raw image while preserving the primary road characteristics. The transformation also converts the road edges into predominant near-vertical components of the image. Therefore a more specialised and simple algorithm can be used for feature extraction. The temporal and reasoning system implemented has demonstrated another major improvement compared with previous road following algorithms. It can deal with missing road edges in situations where they can be masked by shadows, puddles, road marks or in situations where only one side of the road is visible.

Overall, the algorithm has shown some very robust behaviour due mainly to the two new components of the method. Although the algorithm has very powerful characteristics, its implementation does not require dedicated image processing hardware and has been implemented in a single transputer. This provides opportunity to explore parallel processing technology with the addition of more complex interpretation tasks such as obstacle avoidance, road junctions and path planning.

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