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EFFECTIVE VISION ALGORITHMS FOR DETECTION OF STRUCTURED AND UNSTRUCTURED ROADS

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ABSTRACT

For an automatic co-pilot designed to assist the driver while operating a vehicle on well-marked or unmarked roads algorithms were developed for recognizing and tracking the driving lane used by the vehicle. A video camera is used as a sensor. Each algorithm has been implemented on one parallel processor of the multiprocessor robot vision system BVV 3. The method of controlled correlation is used for a quick and robust feature extraction for well-marked roads. To further increase its robustness the program utilizes a 2-D model representing knowledge of the appearance of roads and lane markers in the image of the camera. The algorithm has been tested successfully in simulation and in real-world experiments while driving on different types of roads at high speeds. A far look-ahead distance of 100 m has been achieved, adequate for driving at high speed. For the more complex environment of an unstructured road an algorithm, based on the information of texture, is necessary. Depending on the texture transition it describes a pathway model for autonomous vehicles to operate on unstructured roads.

INTRODUCTION

One of the main subtasks of a robot vision system for autonomous driving on highways or rural roads is to detect and to track the pathway in front of the vehicle. This subtask is part of the basic feedback control mechanism that keeps an autonomous vehicle on the desired path (i.e. the own lane of a multilane highway). In addition, it assists other modules, such as obstacle recognizers, during their operation.

An algorithm for automatic recognition of pathways is confronted with a multitude of scenes and environmental conditions. The possible pathways may be divided into two broad categories:

- Roads with lane markers; the markers may be solid or broken white or yellow lines, according to normal standards.
- Pathways without special markers; this includes unmarked highways (i.e. highways under construction) and unpaved lanes (i.e. country lanes, field lanes) as well as open terrain (meadows, acres, fields, etc.).

There are two versions of the pathway recognition program. One is specialized for well-marked roads; it is based on the recognition of painted lane markers. The other one is based on the surface texture of roads and recognizes unmarked roads and allows cross-country driving.

Ideally, marked roads may be recognized easily in the image, because lane markers are designed to be well visible. Besides, much *a priori* knowledge of the appearance of such roads in the image is available. But in reality, the lane markers are often difficult to be recognized in an image. They may be occluded, for instance, by vehicles in front of, or passing, the own vehicle, or by leaves on the road; also the image may be cluttered with many other confusing features caused by irregularities of the road surface, e.g. skid marks, dark shadows, or rain puddles.

For unmarked lanes different model knowledge must be applied and other features must be evaluated. In this case, the homogeneity of the surface ([Moebius 86]) has to be taken into consideration. This is achievable by adding a texture-based method to segment images. The texture-based segmentation algorithm not only divides the image into road and non-road regions but may also give clues to areas which may belong to objects and junctions.

The present pathway tracker makes it possible to recognize the own lane in front of the vehicle up to a distance of about 100 m for highways and about 60 m for off-road pathways.

DESCRIPTION OF THE ALGORITHM FOR WELL-MARKED ROADS

To detect the pathway in the image, characteristic features on both sides of the road are searched. Features may be either edges (gray-level discontinuities) or lines (pairs of two gray-level discontinuities). To keep the computing time at a minimum, the method of controlled correlation [Kuhnert 86; 88] is applied for feature extraction. The algorithm has been implemented on one parallel processor (Intel 80386/20 Mhz) within the robot vision system BVV 3 [Graefe 90]. The cycle time of the pathway tracker is 40-60 ms, depending on the complexity of the image sequence. The pathway boundaries are first searched near the bottom of the image where they are well visible. Once the boundaries have been detected they are followed upwards in the image.

To obtain both, a reasonable cycle time and a high robustness, the extractable features must be searched in suitably selected search areas. The criteria for the selection of feature candidates and search areas depend on the location in the image; therefore, this algorithm is divided into three phases (Figure 1) as described in the sequel.

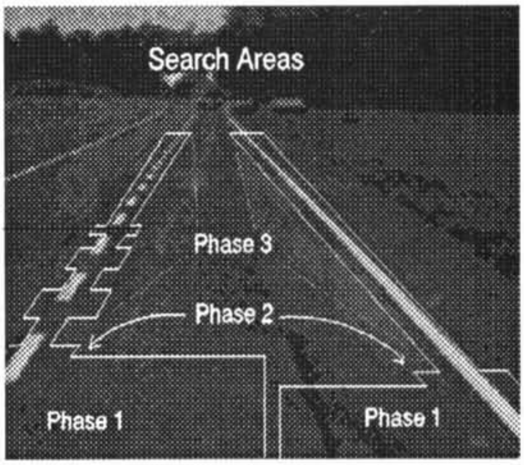

Figure 1
The search areas of the road tracker

Description of the Three Phases

Phase 1
The objective of phase 1 is the detection of the pathway boundaries close to the lower image border. Since, during this phase, only little is known about the orientation of the lane boundaries, edge detectors of low orientation selectivity are applied. Such edge detectors have a relatively high sensitivity against noise. The detected pair of edges, which are exceeding a certain threshold, are accepted as line candidates.

Phase 2
In phase 2 the detected line candidates are measured in regards to their position and direction. This includes determination of their slopes and their exact positions in the image. The search areas are centered around the locations of the edges as found in phase 1.

Straight lanes as well as curved ones are recognized correctly in this phase. False features, such as stains on the road that are sometimes detected erroneously in phase 1, are usually recognized and rejected in phase 2.

Phase 3

Beginning with locations and directions as determined in phase 2, the lane markers are followed upwards in the image step by step in phase 3. With each step the markers are searched within a horizontally extended search region that is centered around the expected position. The noise insensitivity of correlation-based edge detectors allows the tracking of lane markers to a far distance, where they are hardly recognizable due to their faint contrast. This phase is described in more detail in [Tsinas, Graefe 92].

DESCRIPTION OF THE ALGORITHM FOR UNMARKED ROADS

The pathway recognition algorithm for unstructured environment is a multi-stage procedure. At first, the image is segmented into pathway and non-pathway regions. This is done by using a texture operator. Thus, an overview is achieved where the pathway is located within the image. Due to the coarse resolution of the segmentation process and to false-classification of regions, an additional step is necessary to obtain the correct location of the pathway in the image, using some edge detectors. This algorithm has been implemented on one parallel processor within the BVV 3. The cycle time is about 250-400 ms, dependent on the complexity of the image sequence.

Image segmentation with a texture operator

A pathway is characterized by a relatively homogenous region in the image and thus by a region of low contrast. The regions besides the pathway are normally strongly structured and, therefore, appear as regions with high contrast. This property is the basis for the texture-based segmentation of pathway images. A texture operator suitable for this task was described by [Liu, Wershofen 92] in detail.

In the segmented image the borders between pathway and non-pathway regions are searched and classified into right pathway boundary candidates and left pathway boundary candidates. Hereby, a left pathway boundary candidate is characterized by a transition from non-pathway region to pathway region; a right boundary candidate by the opposite transition.

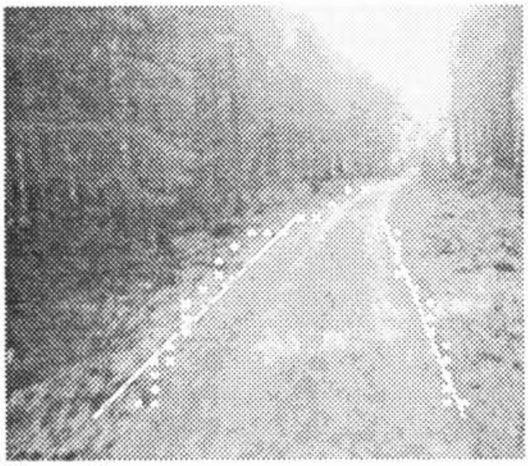

Figure 2
A result of the pathway detector. The dots show the found road boundaries, and the lines the safe pathway.

Detection of the pathway boundaries

In pathway images strongly structured regions may occur e.g. in parts besides the pathway, or in regions where edges of objects appear. Also shadows on the pathway may be considered as structured regions.

For this reason, the original grey-value image is applied to check those boundary candidates by using controlled correlation to determine whether true pathway boundaries exist. This is necessary to obtain the correct location of the pathway boundaries and to reject those boundary candidates that belong, for example, to shadows, inhomogeneities of the pathway surface, or edges of objects.

The correct recognition of the pathway boundaries depends strongly on the quality of the segmentation step. A low number of false classifications of regions leads to a robust pathway boundary recognition. In the extreme case of bad segmentation it may be possible that edges, belonging to other objects in the image, are recognized as pathway boundaries. A modeling of the pathway boundary as a nearly straight line may help to reduce such errors (Figure 2).

EXPERIMENTAL RESULTS

In the beginning, the algorithms were developed applying a PC emulating one parallel processor of the real-time image processing system BVV 3.

During the next step, the algorithms were tested on the robot vision system BVV 3 with real scenes that had been recorded on video tapes while driving at a speed of 40-90 km/h. The recorded scenes were replayed and processed by the vision system in the laboratory in real time. This development phase permitted experiments under dynamic conditions and further refinement of the individual programming stages.

Finally, the algorithm for marked roads was tested during fully autonomous driving with the test vehicle VITA [Ulmer 92] where the system proved its robustness in real time. Lane recognition was possible even during difficult and uncooperative situations, for example, during rain, roads covered with puddles, and during sunshine causing heavy shadows and reflections on the partly wet road.

CONCLUSIONS

Algorithms for detecting and tracking well-marked or unmarked pathways have been developed. Their combination forms the basis of a vision-based processing system for real-time recognition for autonomous road vehicles. Implementations of the algorithms on the real-time vision system BVV 3 were first tested in real time using video tapes. Furthermore, they were tested and used in real-world experiments during autonomous driving. The tests proved their high robustness.

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