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Road recognition for vision navigation of an autonomous vehicle by fuzzy reasoning

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Abstract

This paper presents a method for vision navigation of an autonomous vehicle by road recognition based on fuzzy reasoning. A mobile robot that operates in out-door environments requires fast image processing, noise protection, and robustness to environment changes. Some researchers use fuzzy inference for edge detection. Their idea is to classify a pixel in an original image into a border region or a uniform region according to luminance differences between the pixel and its neighboring ones. In this paper it is studied that for robot navigation some special knowledge is integrated into a fuzzy rule base to recognize road edges based on an approach for general edge extraction. This method is implemented on the THMR-III mobile robot. Some experiments show that this method yields satisfactory results in noise protection, and robustness to environment changes. © 1998 Elsevier Science B.V.

Keywords: Robotics; Pattern recognition; Artificial intelligence; Image processing

1. Introduction

Road recognition is a key issue in navigating an autonomous vehicle [10]. For example, a detection of white lines on streets or edges on roads is one of the most important steps for robot motion in out-door environments. Different approaches have been proposed for the detection of edges in an image, such as the evaluation of an estimate of the local data gradient or of the local second derivative [3]. These approaches, however, might be infeasible for robot navigation in out-door environments since such a robot requires image processing in real time, noise protection, and robustness to environment changes. To speed up image processing, a simple thresholding algorithm based on statistics is implemented for the THMR-III mobile robot [13]. In experiments, it is noticed that thresholds largely depend on environments, e.g., different thresholds should be determined to process different regions in the same picture to obtain a good performance.

For detection of edges, some approaches based on computational intelligence have been proposed. For instance, one presents algorithms for edge extraction by the use of neural networks [4, 8]. Since out-door environments usually are very complicated, providing complete and efficient patterns with neural networks is a very difficult work. Recently, some researchers have proposed methods for edge

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Fig. 1. THMR-III out-door mobile robot.

detection using fuzzy reasoning for general purpose [1, 2, 11, 12]

This paper presents a method for vision-based navigation of an autonomous vehicle by fuzzy inference [6, 7]. The idea of this study is that some special knowledge is integrated into a fuzzy rule base to recognize edges on roads, based on a fuzzy-logic-based approach for general edge extraction. This method is implemented on the THMR-III mobile robot. Some experimental operations are performed to demonstrate its effectiveness and robustness.

2. Vision system of the THMR-III mobile robot

The THMR-III mobile robot is equipped with a vision system for image processing, which consists of a high-level sub-system and a low-level sub-system, as shown in Fig. 1. The high-level vision sub-system has a pipe, an image box, and a sun workstation; while the low-level vision sub-system has a PC486 computer, a high-speed image processing board VIGP-2M, and two CCD cameras. According to a geometric model of the car body and navigation requirements [13], they are installed on the top and the front of THMR-III robot, respectively. The distance of the top camera from the ground is 2 m; while the distance of the front camera is about 1 m. Image information from the top camera is mainly used to track far roads within the region 8 m – infinity. Image information from the front camera is mainly used to avoid obstacle and to track near roads within region 4–12 m. All images used in this paper are taken by the front CCD camera, for example, the images in Figs. 3(a) and 4(a).

3. Edge detection by fuzzy reasoning

Fuzzy logic inference is based on the theory of fuzzy sets, as introduced by Zadeh [14]. A fuzzy set A in a universe of discourse X is defined by its membership function $\mu_A(x)$. For each $x \in X$, there exists a value $\mu_A(x) \in [0, 1]$ representing the degree of membership of x in X. In a fuzzy logic expert system, membership functions assigned with linguistic variables are used to fuzzify physical quantities. Fuzzified inputs are inferred to a fuzzy rule base. This rule base is used to characterize the relationship between fuzzy inputs and fuzzy outputs. For example, a simple fuzzy inference rule relating input v to output u might be expressed in the *condition–action* form as follows:

- If v is W Then u is Y,

where W and Y are fuzzy values defined on the universes of v and u, respectively. The response of each fuzzy rule is weighted according to the degree of membership of its input conditions. The inference engine provides a set of control actions according to fuzzified inputs. Since the response actions are in fuzzy sense, a defuzzification method is required to transform fuzzy response actions into a crisp output value of the fuzzy logic inference. A widely used defuzzification method is the centroid method [9].

In [11], an idea of detecting edges by fuzzy inference is to classify every pixel in an image into white or black based on the two following strategies:

- if a pixel belongs to a border region then make it black else make it white
- if a pixel belongs to a uniform region then make it white else make it black:

In order to decide if a pixel belongs to a border region or to a uniform region, luminance

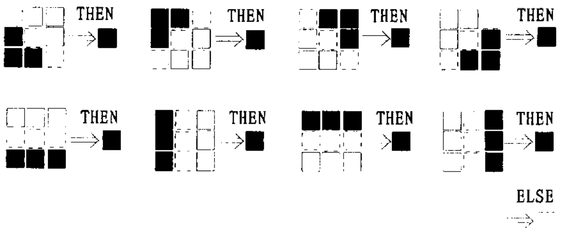


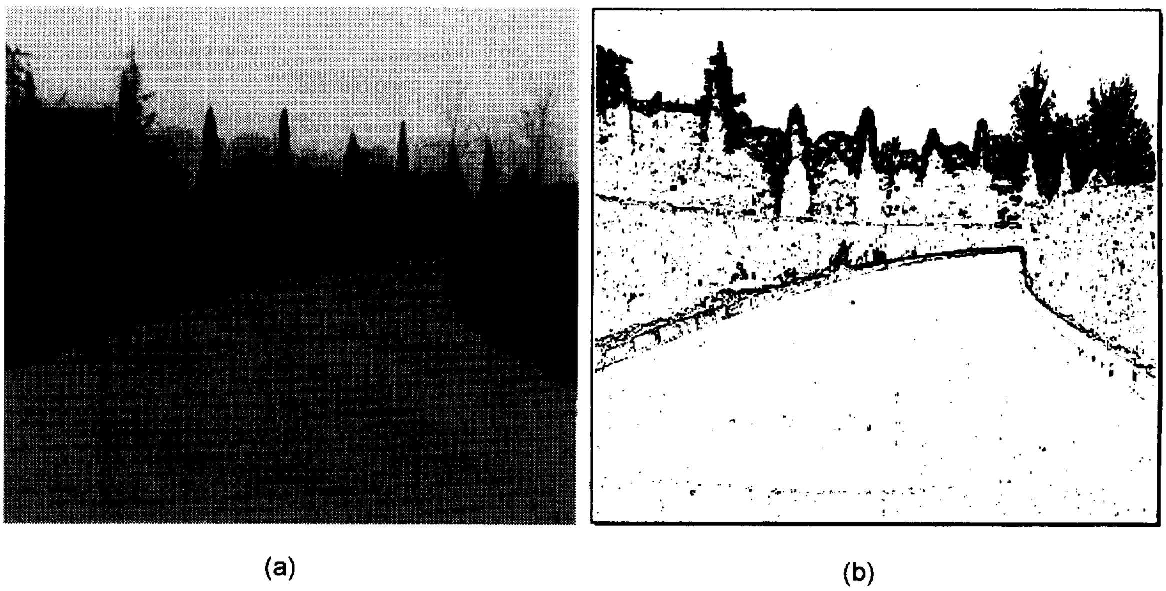
Fig. 2. Rule base of fuzzy logic inference.

differences between the pixel and its neighboring ones are computed. Then, this pixel is processed by the fuzzy rule base. All rules in the fuzzy rule base are shown in Fig. 2. If a pixel meets one of the following conditions, it should be black, that is, it should belong to a border region. Otherwise, the pixel should be white, that is, it should belong to a uniform region. In our paper, all fuzzy sets are defined by triangular functions. In this method, the Max–Min inference and the centroid defuzzification are used. Figs. 3(b) and 4(b) show 512×512 pixel images processed by this algorithm.

4. Robot navigation based road knowledge

In order to speed up image processing, a 512×512 pixel image from the image processing board VIGP-2M is first compressed into a 128×128 pixel image. Then, edges are extracted by classifying pixels into a border region or a uniform region by fuzzy logic inference. In this step, noise in an image is filtered, and edges in the image are detected. Finally, images yielded by fuzzy logic inference are binarized. If there is not much noise on roads, such processed images could be used to plan a path for robot motion. For example, Fig. 3 shows an experimental environment. In this case, road edges are detected due to luminance differences between roads and tree walls. It can be seen that the binarized black–white image in Fig. 5 presents clear road edges for path planning.

In most applications, however, there exists much noise in an original image. For example, Fig. 4(a) shows an experimental environment under strong solar reflections. In this case, road extraction becomes difficult. To deal with this problem, we integrate special knowledge on features of roads into



(a) (b)

Fig.3. Robot motion in environment 1.

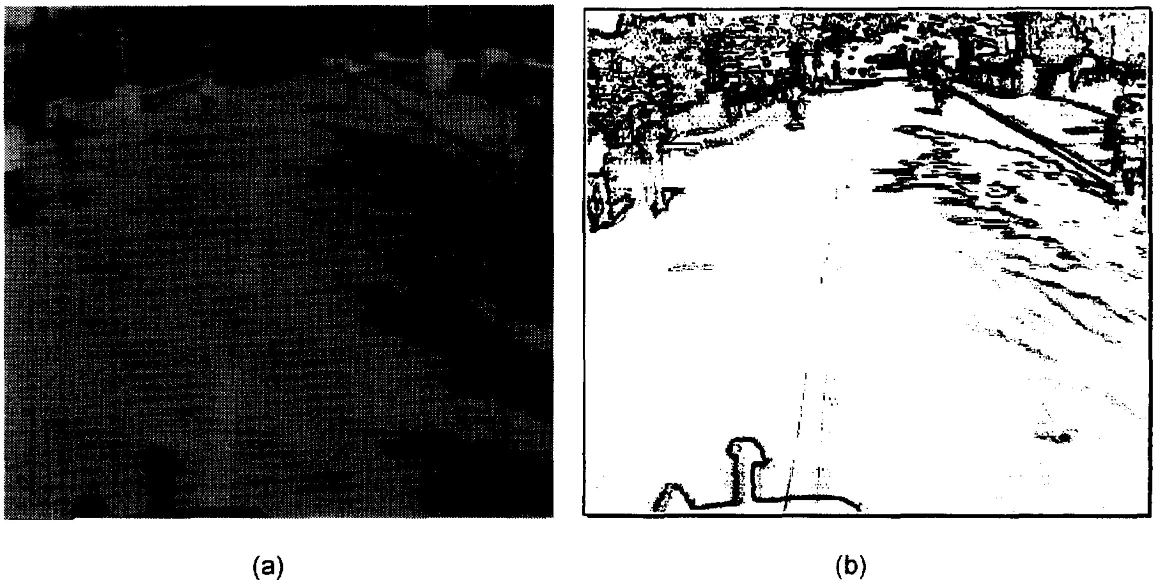


Fig. 4. Robot motion in environment 2.

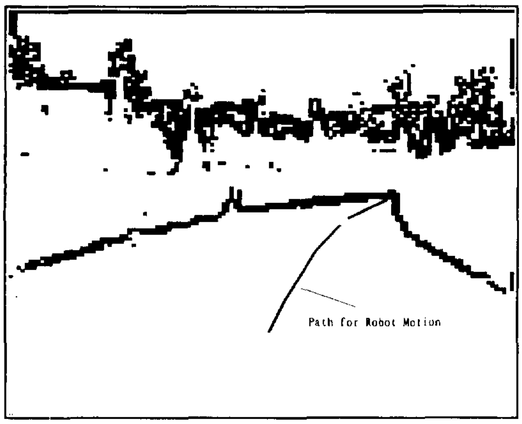


Fig. 5. Path planning according to road edges.

a fuzzy rule base. In doing this, we propose the following modified strategies:

- if a pixel belongs to a border region and *it is close to a feature* then make it black else make it white
- if a pixel belongs to a uniform region and *it is close to a feature* then make it white else make it black.

For vehicle motion, a road map is saved in computer memory as knowledge. In this study, road edges are classified into both types of straight and curved edges. In our experiment, the road map of the Tsinghua University campus is adopted to indicate what type of road edges the vehicle should follow. If the road map indicates that an edge is straight, the edge is represented by a line equation; when the road map indicates that an edge is curved, the edge is represented by a parabola equation. In order to build a template of a road edge, its initial points on the road edge should be determined. Because a road edge is usually continuous, several points of the road edge are calibrated before the vehicle run. According to the type of a road edge and its initial points, we can define a membership function for an edge template T_s, as shown in Fig. 6. The parameter dp is the shortest distance of a pixel P to the edge template T_s. On the basis of this membership function, a weight $w(dp)$ is computed using the shortest distance. When the vehicle runs, it determines if a pixel P in an original image belongs to a road edge or not by the following steps:

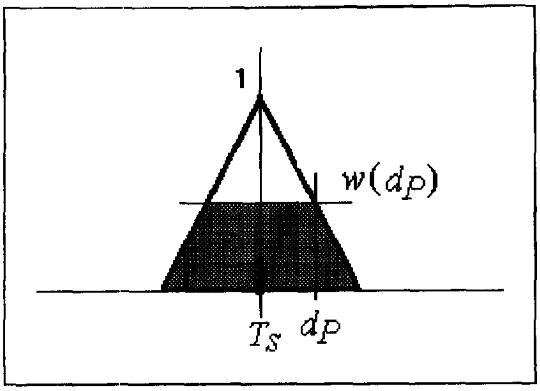


Fig. 6. Membership function for a road edge template.

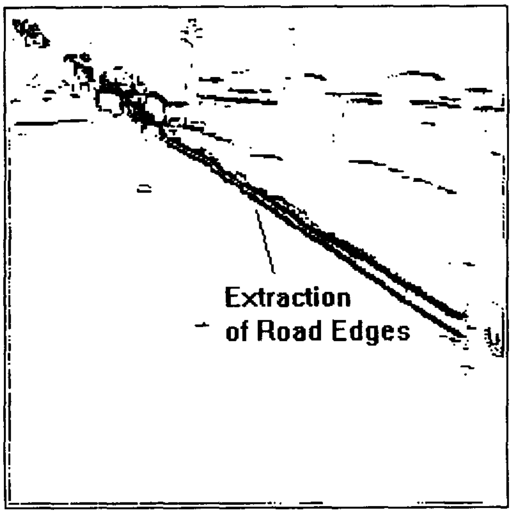


Fig. 7. Road edge extraction.

Step 1: Compute luminance differences of the pixel P, *Lum_Dif*(i) ($i = 1, \ldots, 8$), of its neighboring pixels;

Step 2: Based on the membership functions defined, fuzzify the luminance differences, *Lum_Dif*(i) ($i = 1, \ldots, 8$), according to THEN-RULES in Fig. 2 to obtain $w(i)$ ($i = 1, \ldots, 8$);

Step 3: Determine initial points of an edge template according to the last processed image.

Step 4: Compute the shortest distance of the pixel, dp, to the edge template, and compute a weight $w(dp)$, based on the defined membership function in Fig. 6;

Step 5: Use $w(i)$ and $w(dp)$ to compute the strengths of THEN-RULES and ELSE-RULES by MIN–MAX inference;

Step 6: Classify this pixel into white or black by the centroid defuzzification.

Fig. 7 shows a right edge road that is extracted from the environment in Fig. 4. It can be seen that shades of trees and other noises have been removed. This extracted edge can be used for robot navigation.

5. Conclusion

This paper has presented a new method for vision-based robot navigation in out-door environments. This method for the detection of road edges is not sensitive to noise. Here, it should be noticed that the fuzzy rule bases for processing both the images in Figs. 3(a) and 4(a) are identical. This result is very useful for robot navigation because of the robustness of the fuzzy logic inference to environment changes. Besides, this method can be combined with low-level reactive behavior control to improve performance of robot motion [5].

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