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Stop-sign recognition based on color/shape processing

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Abstract. This paper presents a robust vision-based stop-sign reconition technique based on sequential processing of color and shape. The primary red-green-blue color coordinate system is first transformed into the saturation-hue-brightness color coordinate system. This color coordinate system allows the red color area of a stop sign to be bounded under various brightness conditions caused by weather, sun angle, or shadows. A combination of a median filter, a morphological filter, Sobel edge operator, and Hough transform is then employed to obtain the boundary contour. It is demonstrated that the parameters of eight straight lines representing the octagonal sides are sufficient for this purpose. Experimental results indicate that stop signs are successfully distinguished from other traffic sighs and background clutter.

Stop-sign recognition – Color/shape processing – Advanced driver information systems

1 Introduction

Advanced Driver Information Systems (ADIS) has been recognized as an integral part of Intelligent Vehicle Highway Systems (IVHS) (Rillings J 1989). IVHS compromises a series of projects designed to improve traffic flow and safety of highways in the United States. One of the ADIS functions includes the development of safety warning mechanisms against collision, skid, stop signs, and similar hazardous driving conditions. In this paper, we discuss a stop-sign recognition algorithm that can be used in future vehicles to warn drivers that they are approaching a stop sign at an intersecton. It is assumed that the vehicle is equipped with a video camera providing color images of the navigational environment.

The treatment of traffic signs by computer vison techniques has been fairly limited in the literature. A noteworthy work has appeared in (Blancard 1990) where shape processing is used for recognition of traffic signs. In our approach we have used color processing and shape processing sequentially in order to ease the difficulty of removing false edges introduced by brightness changes and shadows. By color processing the scene is reduced to a sparse edge map of red objects, which is then analyzed by shape processing. A hardware implementation of such a hybrid approach has been presented in Akatsuka and Imau (1987) where the three primary colors are used to extract a speed-limit sign.

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2 Recognition algorithm

The block diagram of the recognition algorithm is shown in Fig. 1. This diagram includes two phases: color processing and shape processing. Each of these phases will be described.

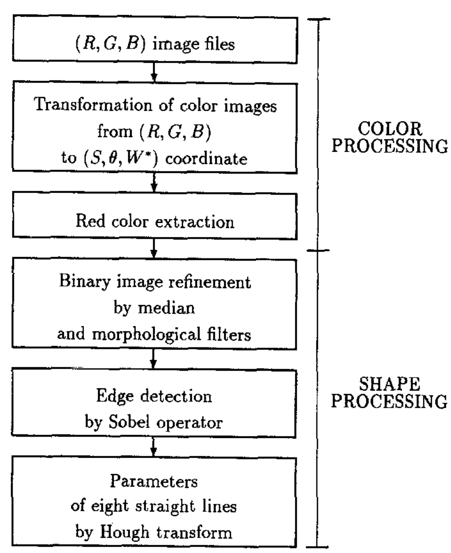
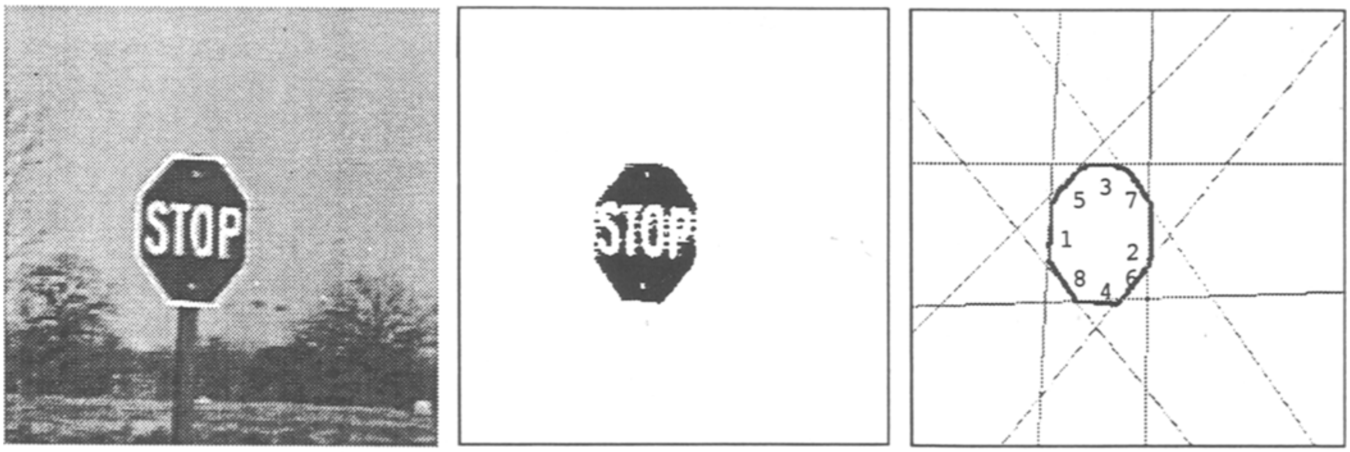


Fig. 1. Block diagram of the stop-sign-recognition algorithm

2.1 Color processing

A scene captured by most color image processing systems is represented by three primary images, namely, red, green, and blue. A typical green image of a stop sign is shown in Fig. 2a. Different color-coordinate systems have been introduced for color processing. A thorough list appears in (Pratt 1978). As the first step towards stop-sign recognition, the saturation-hue-brightness system (S–θ–W^*) is employed to



a b c

Fig. 2. **a** A stop-sign image; **b** extracted red-region binary image; **c** eight lines representative of the boundary contour

Table 1. Parameters for the contour of Fig. 2c. d, distance; α orientation

line number	d	α	$\lvert d_i - d_j \rvert$
1	29	87	18
2	47	89	
3	30	0	28
4	58	2	
5	45	45	22
6	67	51	
7	16	126	27
8	−11	129	

extract red hues as perceived by humans. This system is chosen in preference to the primary red-green-blue system (R–G–B) because of its capability to reject unwanted color shades. For example, the green component of (R–G–B) still contains a considerable amount of red and the red component contains green and some blue. In primary images this color leakage appears as black and white shades. In the (S–θ–W^*) system the hue component rejects black and white shades. As a result nearly the same regions that are perceived as red by the human visual system are extracted from the images.

A statistical study was performed for the purpose of bounding the subspace of the (S–θ–W^*) color space which contained the red of stop signs. The red of stop signs was mapped into the (S–θ–W^*) color space for a large number of stop signs with different backgrounds and ambient lighting conditions. This study indicated that stop signs are contained in the subspace spanned by $S \geq 15$, $3° \leq \theta \leq 56°$, $W^* \leq 84$. These values are then used as discriminant functions to segment possible red stop signs. A binary image is formed by using only those points whose (S–θ–W^*) components are within this subspace. Fig. 2b illustrates the binary image obtained from the primary images of the stop-sign shown in Fig. 2a.

2.2 Shape processing

In this phase, first the boundary contour of the stop sign is extracted. Then the shape of the contour is verified to be an octagon. This is done in the following manner. The color processed binary image is refined by passing it through two filters. The first, a median filter, removes isolated spots while preserving the edge information. The second, a dilation/erosion morphological filter, removes discontinuities and masks the letters inside the area of the stop sign. At this stage the Sobel edge operator is applied to extract the boundary contour as shown in Fig. 2c. The detected boundary contour is then represented by eight straight lines parameterized by their perpendicular distance d from the origin (at the upper left corner) and the angle between the perpendicular line and the vertical axis (or orientation) α. The distance d and orientation α are obtained by using the Hough transform technique. The eight highest peaks in the Hough parameter space (d, α) are then used to indicate the eight strongest lines. Consequently, spurious lines consisting of only a few points are disregarded. The straight lines must have one of the orientations 0°, 45°, 90°, and 135°. In order to tolerate shape variability, the following ranges are considered for the above four orientations: (0°–3°, 177°–180°), (42°–59°), (87°–93°), and (125°–140°). The orientations 45° and 135° have wider ranges on one side than on the other for the purpose of including elongated images. Such images are obtained when a sign is not located on the optical axis of the camera (i.e., when the optical axis is not normal to the plane of the stop sign). As a result the projection of the sign onto the camera image plane appears skewed or elongated.

The distance and orientation parameters for the contour in Fig. 2c are tabulated in Table 1. A stop sign is detected if the distances between the lines having the same orientation (i.e. $\lvert d_i – d_j \rvert$'s) are not zero and the ratios of each distance to any other larger distance are greater than one-half. It should be noticed that our approach allows the recognition of a stop sign regardless of its position and size in the image.

Table 2. Summary of experimental results

Signs	$\|d_1 - d_2\|$	$\|d_3 - d_4\|$	$\|d_5 - d_6\|$	$\|d_7 - d_8\|$	Recognition
Stop 1	18	28	22	27	$0.5 \leq$ ratios ≤ 1, yes
Stop 2	14	22	16	21	$0.5 \leq$ ratios ≤ 1, yes
Stop 3	12	16	12	10	$0.5 \leq$ ratios ≤ 1, yes
Stop 4	21	28	26	23	$0.5 \leq$ ratios ≤ 1, yes
Stop 5	27	28	26	20	$0.5 \leq$ ratios ≤ 1, yes
Do-not enter	4	32	0	27	ratios < 0.5, no
Yield	2	0	0	9	ratios < 0.5, no
Bicycle	4	2	0	6	ratios < 0.5, no
Curve road	2	10	0	12	ratios < 0.5, no
Pedestrian crossing	2	0	0	15	ratios < 0.5, no
Speed limit	0	0	0	3	ratios < 0.5, no

Therefore, it constitutes a robust approach for recognizing stop signs.

3 Experimental results

Table 2 summarizes the results for five stop signs, a do-not-enter sign, a yield sign, a bicycle sign, a curve-road sign, a pedestrian-crossing sign, and a speed-limit sign. For traffic signs containing no red colors (bicycle sign, curve-road sign, pedestrian-crossing sign, speed-limit sign) some of the distances were zero, which led to the rejection of these signs by the octagonal shape constraints. These constraints were also violated for traffic signs having red colors (do-not-enter sign and yield sign). Stop-signs with different backgrounds at different distances and therefore sizes were tested. All of the stop signs were successfully recognized at a distance as great as 150 ft. The camera parameters consisted of a field-of-view of 43°, a focal length of 11 mm, a tilt angle of 0°, and a height of 5.5 ft. Beyond this distance the recognition algorithm could not distinguish a stop sign from a do-not-enter sign because of the resolution of the images. It is worth pointing out that it is possible to activate a second processing module to recognize the word 'stop' after getting close to the stop sign. The size of the word and the sign itself are a function of the field-of-view, focal length and size of the image plane. If the image at 300, 100, or 50 ft has only a few pixels, we are limited by the resolution. However, the shape and color will be distinguishable before the word 'stop'.

Conclusions

A hybrid color/shape recognition algorithm has been developed as part of a warning system for approaching stop signs. The algorithm uses both red color and octagonal shape attributes of a stop sign to distinguish it from other traffic signs. The algorithm was tested on a large number of signs of various types and backgrounds. Stop signs were successfully recognized at distances of less than 150 ft under different brightness conditions. This research contributes both experimental information for subspace bounds and a sign segmentation approach for discriminating stop signs from other signs in cluttered backgrounds. It therefore demonstrates a practical application of vision techniques for ADIS technology.

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