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Real-Time Recognition of Signaling Lights in Road Traffic

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ABSTRACT

A method for recognizing signal lights in traffic scenes in real time has been developed. It consists of a set of different feature extraction operations acting as sequential filters. In order to be classified as part of the image of an active signaling light, a set of pixels must pass each one of these filters. This multifilter approach is model-based, and it comprises much of the available knowledge about signaling lights. In addition to color, this includes characteristics like the locations of the lights relative to the vehicle, their size, symmetry, and blinking frequencies. The individual filters, and the way how they cooperate, have been designed in such a way that the system recognizes active signaling lights reliably, while false alarms are largely avoided.

We have implemented the approach on a real-time vision system and tested it both in simulations under approximately real conditions and in real highway scenes by using a robot-car.

Introduction

Automatic systems that support the drivers of motor vehicles, either by warning them when a dangerous situation begins to develop, or by driving the vehicle automatically at least part of the time, have a great potential for improving the safety of road traffic. Steps towards the realization of such systems have been described, e.g., by [Graefe 1992].

The continuous recognition of dynamically changing traffic situations in real time is a key issue for these systems. Part of this problem is the recognition of light signals emitted by other vehicles indicating the activation of the vehicle's brakes, the intention of the driver to change the direction of the vehicle, or some emergency condition. In most countries all motor vehicles are required to have signaling lights for such purposes, and the drivers are required to use them appropriately. Extensive regulations regarding the characteristics of the signaling lights exist. All this shows how important for traffic safety the installation and use of such signaling devices are considered to be.

For humans, recognizing signaling lights is usually very easy, but it is largely unclear how the human visual system can accomplish this task. In principle, both chromatic and achromatic characteristics of the signals may be utilized, and it appears that for humans the color of the signaling lights is of considerable help in the recognition process. Therefore, we decided to include color features in the process of automatic recognition, too.

Governmental regulations controlling the permissible properties of signaling lights under ideal conditions, and empirical observations of their actual appearances and of the ways how drivers use them in various traffic situations constituted an additional source of knowledge for designing the recognition system. This will be discussed in the paper.

Although color is helpful for recognizing signaling lights, by itself it is not sufficient. The characteristics of real signaling lights, together with the imperfections of available cameras and image processing systems, impede implementing a simple color filter concept. These characteristics and imperfections, especially the ones related to cameras, will be discussed, together with their consequences on the algorithms that were eventually implemented.

Features of signaling lights

In this paper the term „signaling lights" refers to three types of lights that are carried by all motor vehicles: indicators, brake lights and emergency flasher lights.

In governmental regulations the color of signaling ligths is given in [CIE 71] color components (x,y). They are precisely diffined regions for the red and yellow colors, which are measured in a fixed environment with constant illumination (Fig. 1). Such conditions are not given, when a car is driving on highways under varying wheather and illumination conditions.

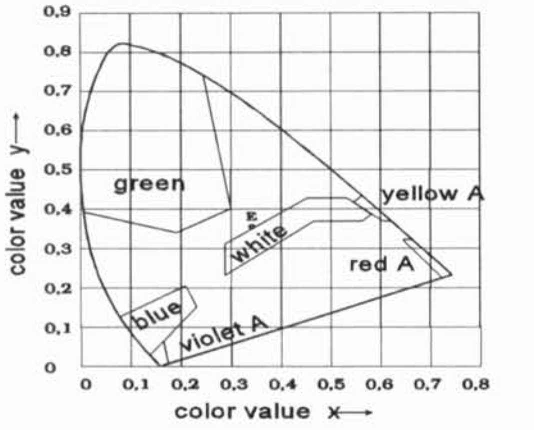

Figure 1

The allowed color components for signalling lights [DIN 6163] in CIE color coordinates.

Therefore, we have analyzed the actual color of signaling lights as they appeared in the digital images of traffic scenes that were processed by our vision system (Table 1). For this purpose we have defined a novel color representation that we have termed ISH (intensity, saturation and hue). ISH is a derivative of the HSI color space [Tennenbaum 1994]. When the original RGB values are transformed into our ISH color space we use, instead of the original HSI hue transformation algorithm, the one proposed by Smith [Smith, 1978]. The advantage of this modification is that Smith's transformation is much faster than the original one if a typical processor is used. Fast hue transformation is critical in a real-time system if hue has to be computed for many pixels, for instance, when searching signaling lights in an image of a traffic scene without much knowledge as to where in the image the lights are to be expected.

Table 1.
Measured ISH-values for flashing- and stop-lights on a scale of 0 ... 255

	H	S	I
flashing light	230...50	15...50	120..170
stop light	220...10	25...85	90...155

The camera that was available for our experiments [Teli 1993] has an automatic exposure control that tends to stabilize the average brightness of all pixels in the image. While this allows most objects in the scene to be recognized reliably even when the illumination of the scene changes, it often causes the brightest elements of the scene, such as signaling lights (especially when the area covered by them is only a small part relative to the image), to appear overexposed. If this happens the affected sensor elements in the camera operate in a severely nonlinear way, and the apparent color of the associated objects changes significantly and is desaturated. Another imperfection of our and probably of every CCD-camera and A/D-converter is that they cannot offer noiseless measurements. A large number of experimental measurements showed to us, that variations of each color component of ±6 of 255 possible values are typical with usual image processing equipment That means, not only intensity but also saturation and hue are pertained to the variations of their measured values. A reliable recognition of object colors is then impossible. Therefore, additional features are needed for recognizing signaling lights.

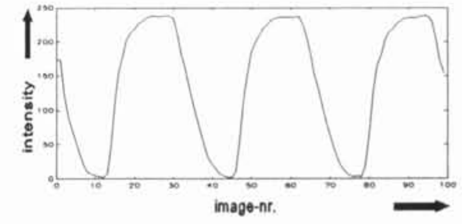

Figure 2

Intensity-diagram of a blinking flashing light (with 20 ms time interval between two image numbers).

Another important characteristic of indicators and emergency flashers is that they emit periodic light pulses. In Germany the pulse frequency should be (1.5 ± 0.5) Hz. Fig. 2 shows the variation of the brightness of a flashing light over time, as recorded by our vision system. The frequency of the indicator is 1.5 Hz.

Recognition of Signaling Lights

The recognition of signaling lights is based on the concepts of dynamic machine vision as proposed by [Dickmanns, Graefe 1988]. The entire process is knowledge-based, and feature extraction is, for reasons of efficiency, limited to those parts of the image where signaling lights may actually be expected to appear.

The Multifilter Concept

Since no single feature by itself is sufficient for characterizing a signaling light, a multitude of features is utilized. This is the essence of the „multifilter concept" proposed here. According to this concept an area in an image is classified as being part of the image of a signaling light if, and only if, all (or at least most) of the expected features have been detected.

Search Area Selection

The multifilter is intended to be part of a larger system designed to assess an entire traffic situation in real time, e.g. [Graefe 1992]. Other modules in such a system are responsible for locating the road, its lanes and vehicles in front of the ego vehicle in the image.

By using information from these modules the operation of the multifilter may be limited to that area within the image where a vehicle has been detected

A further reduction of the image area to be processed by the multifilter may be based on the fact that ordinary vehicles have their signaling lights on the lower part of their body (Fig. 3). In our experiments we used a height limit of 1 m for the search area.

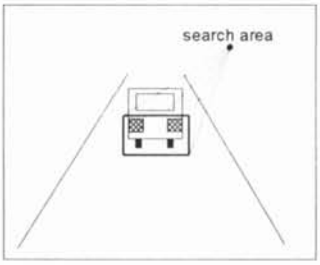

Figure 3

Minimized search area covering only the lower part of detected car

Color

The most significant feature of signal lights is their color. During the recognition process those pixels, that fulfil the color criteria (as expected from Table 1) are classified as (part of) signal light-candidates. This color classification is realized sequentially, beginning with the intensity criterion. If the actual intensity is within the intensity values allowed (in accordance to table 1) the next criterion (saturation) is checked. The last check concerns hue, because, compared to S- or I-computation, hue-computation (from R-, G- and B-values) is computationally much more costly. Therefore, hue is computed only for those pixels that have already passed the I and S filters.

A set of directly adjacent color-filtered pixels is then combined into one image segment by region growing, and considered one object (signal light candidate).

Other Features

A few additional filters complete the verification process for those image sections, which were segmented as signal light candidates.

The size filter checks if the candidate segments have sizes as they may be expected for images of signaling lights. The size range actually used is parameter-controlled, but usually a minimum area of 12 pixels (arranged as 2*6, 3*4, etc. pixels of the 512*512 pixel image-size) is used. This leads to a theoretical maximum detection distance for signaling lights of 40-50 m if a 25-mm tele lens on our camera Teli CS5130P [Teli 1993] is used. The maximum size that is allowed for a signaling light candidate was usually set to 10% of the search area. The inclusion of an upper size limit prevents large objects of reddish or yellowish color from being misclassified as signaling lights.

A temporal filter differentiates between continuously activated and periodically blinking signaling lights. Like a bandpass filter, it allows for the passage of signals (extracted from the image) with frequencies of about 1.5 Hz. A position filter distinguishes between left and right flashing lights.

Implementation

The signal light recognition algorithm has been implemented on a „Transputer Image Processing System" (Parsytec) comprising three main components:

- a „Color Frame Grabber" (CFG) with an Inmos T800 transputer
- a „Versatile Processing Unit" (VPU) with a T800 and an additional T400 transputer and
- a „Color Graphic Display" (CGD), a device for outputting images on video monitors

These components are connected by a video bus that distributes the digitized images from the CFG to the VPU and the CGD.

The task of applying the color filter to the pixels in the search area is divided between the CFG and the VPU (both contain equivalent T-800 transputers). One processor handles the left half of the search area, and the other one the right half. The other filters are applied only to those pixels that have met the color criteria. Only one processor, the CFG, is used for this because the computations needed for these filters are not very time-consuming.

If the pixels of certain image areas have passed all the filters, then the system assumes that it has detected signaling lights. This result is indicated by displaying small white squares at the bottom of the monitor screen that shows the image being processed by the vision system. One square at the left or right indicates that a flashing light on the corresponding side of a vehicle has been detected, and two squares near the center indicate stop lights.

Experiments

The presented algorithm has been tested with numerous sequences of video-scenes that had been recorded on video tapes while driving on the Autobahn at a speed of about 100 km/h. The recorded scenes were played back and processed by the vision system in the laboratory in real time.

In these experiments the vehicle detection module that would normally guide the placement and size of the search area in the image was not present. The search area was, therefore, controlled by an operator via the keyboard.

In the experiment the algorithm proved able to detect signaling lights reliably. Example 1: a 6 min video sequence with 79 left and right indicators and also five appearances of braking lights each of them with 5 to 7 sec duration was given to be tested. All of the 79 indicators where finded correctly. From the braking lights only one appearance was not detected, because the distance to the car in front was about 100 m and the representation of the braking lights on the digitized image included only a few pixels. Recognition of such small image parts as signalling light(s) is not allowed by the algorithm. A variety of other scences with other illumination conditions brought similar results.

Detection of signaling lights was also able by using the 'seeing passenger car' VaMoRs-P. In the autonomous mobile robot VaMoRs-P the car finder ODT had been installed [Thomanek, et al. 94] and was used for the search area selection. They are not other main differences between both experimental environments. Example 2: a car driving in front was examined for signal light activity. They were found with the same robustness and limitations as in the laboratory environment. The computing time for processing an image area of 250*50 pixels (example 1) is about 80-100 ms (4-5 video cycles).

When signaling lights have been detected they are tracked. The search area for tracking is much smaller than for the initial detection. It is placed around that position in the image where a signaling light has been detected in a preceding image. The cycle time during tracking is, therefore, only 20 ms.

Limitations

The main problem is the poor discrimination between different types of signaling lights. The predominant cause is the limited ability of the camera to provide accurate color values. The color values of flashing lights and brake lights as registered by the camera are often very similar, or even identical. This happens mainly when the brightness of the lights exceeds the linear operating range of the camera. A monochrome camera whose sensitivity can be directly controlled by the vision system was described by [Graefe, Albert 1995]. If a color camera of this kind were available it might be expected to give much better results under difficult lighting conditions.

For practical reasons we have limited our experiments to the signaling lights of cars. There is, however, no reason to doubt that the algorithm would also detect the signaling lights of other vehicles, such as trucks, buses or motorcycles.

Conclusions and Outlook

A novel method for recognizing signaling lights (direction indicators, emergency flashing lights and brake lights) in highway traffic scenes has been presented. At the core of the method is a set of cooperating feature filters that together detect signaling lights in natural traffic scenes with good reliability.

This multifilter concept was implemented as a real-time process within a multi processor vision system. A novel color space representation was developed for this purpose to allow color information to be processed in real time without any special-purpose hardware. It is similar to the well-known hue-saturation-intensity representation, but it allows the hue-related information to be processed more efficiently on most processors.

The recognition system was extensively tested in a variety of traffic scenes. Activated signaling lights of vehicles were recognized with good reliability, provided the distance from the emitting vehicle was not too great (less than about 50 m). The relationships between camera settings (aperture and shutter) and the resulting brightness and color values in the image are mirrored in some filters of the the multifilter concept.

A method for recognizing the activation state of signaling lights is, thus, ready to be integrated into future automobile driver support systems and to contribute to an improvement of traffic safety.

Future work may concentrate on achieving higher system robustness, especially by using newer cameras with a greater dynamic range.

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