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Recognition of occluded traffic signs based on two-dimensional linear discriminant analysis

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ABSTRACT

Traffic signs recognition involving digital image analysis is getting more and more popular. The main problem associated with visual recognition of traffic signs is associated with difficult conditions of image acquisition. In the paper we present a solution to the problem of signs occlusion. Presented method belongs to the group of appearance-based approaches, employing template matching working in the reduced feature space obtained by Linear Discriminant Analysis. The method deals with all types of signs, regarding their shape and color in contrast to commercial systems, installed in higher-class cars, that only detect the round speed limit signs and overtaking restrictions. Finally, we present some experiments performed on a benchmark databases with different kinds of occlusion.

KEYWORDS: Traffic sign recognition, linear discriminant analysis, classification, occlusion

1. Introduction

The evolution of current transport systems can be analyzed at different scales: infrastructure, power sources, vehicle types, information systems etc. One of the most important, from the practical point of view, is vehicular automation. After the introduction of digital circuits to almost every car in the world, the complexity of automation technology increased. Nowadays, that manufacturers consequently add a variety of automated functions to automobiles and other vehicles.

Generally speaking, vehicular automation connects different elements of mechanics, electronics and artificial intelligence to support a vehicle's operator. Taking above into consideration, one should remember that, a human is still the one, who operates the vehicle and, unfortunately, can be disrupted [15].

One of the most important aspects in terms of vehicle operation is perception of traffic signs. It has an influence on road safety. This problem is related, among others, to some psychological aspects of human vision and is influenced by independent environmental conditions.

To help humans in above tasks the researchers and manufacturers introduced a Traffic Sign Recognition (TSR) technology, which is a part of the features collectively called Advanced driver assistance system (ADAS). It enables a vehicle to recognize traffic signs put on the road. Most of such systems use a video camera (working in visible and infrared range) and an integrated circuit implementing computer vision algorithms.

One of the first TSR systems was developed and appeared on the market in 2008 (BMW 7-Series, Mercedes-Benz S-Class). Unfortunately it detected only the round speed limit signs to be found in most of European countries (e.g.[1]). A detection of overtaking restrictions is performed by more complex systems. Such an exemplary system was introduced in 2008 in cars made by Opel and used by other car-makers in their products (2011, Volkswagen; 2012, Volvo).

The main constraint of systems installed in current cars is the limited number of sign types that can be recognized and the low robustness to environmental conditions. However, the rapid progress in this area suggests that more advanced systems may be available in near future [8]. It should be also noted, that the practical implementation of above systems is far behind the methods developed by researchers. Selected approaches related to the recognition of more signs' types will be presented in the further part of the paper.

The most important problem we are facing today is a robust and reliable recognition of signs observed in complex, unpredicted outdoor conditions. While the recognition in laboratory controlled environments reach almost perfect accuracy, the real-world situations negatively affects the successful recognition. In practice, the level of light is often not sufficient, the quality of signs and their light-reflective surface degrades over time. The signs are often occluded, painted, covered by snow and leafs. Several exemplary signs that are hard to recognize by automatic systems are presented in Fig. 1.

Fig. 1. Exemplary signs photographed in real-world conditions, affected by different kinds of occlusion

In this paper we provide a method based on visual recognition of traffic signs that can deal with occlusions. We assume to have a fully localized and extracted area that contains sign. Then, we perform a classification in the reduced feature-space. The reduction is obtained by means of Linear Discriminant Analysis, which has in been used to reduce the dimensionality and cluster different data types.

The review of the literature shows that the authors do not often use direct LDA approach for problems involving high-resolution image, since it requires to perform a decomposition of large covariance matrices, and in such case the number of samples should be significantly larger than the number of classes.

Hence we investigate an application of two-dimensional LDA, which involves two small-sized covariance matrices and the number of samples per class in significantly lower than in classical approach [16].

1.1 Visual recognition methods

Traffic sign detection and recognition are still challenging problems that characterizes high practical relevance. So far, many methods have been proposed. Exemplary comparisons of several approaches were published in [8] and [9].

Humans are capable of detecting the large variety of existing road signs with close to perfect reliability in experimental setups. This does not obviously apply to real-world driving, where the drivers attention is regularly drawn to different tasks and situations.

Typically, the problem of TSR is solved by two subsequent processes. The first one is devoted to sign detection and localization while the second one, is associated with actual sign classification (recognition). The first stage is often based on low-level shape and color features (traffic signs are simple and regular objects of specified shapes and colors). It should be noted, that traffic sign detection is a search problem in natural (outdoor) images. A useful detector must, therefore, be able to cope with rotation, different lighting conditions, perspective changes, occlusion and all kinds of weather conditions. Hence, during the creation of learning database a special care should be taken on a diverse and representative compilation of single image frames.

The second stage employs different feature extractors (geometrical, like SIFT [6][7][11] or LESH [10] and color – dominant colors [1] and low-frequency components of Discrete Cosine Transform [12]). The features are then reduced using linear subspace methods, i.e. Principal Component Analysis [11][14] and Linear Discriminant Analysis [2]. Finally, a certain classifier is employed (Adaboost [11], Support Vector Machine [10], Bayes, Artificial Neural Networks [1][5]) in order to make a decision, which sign we have. The accuracy of proposed systems is calculated as a percent of correctly identified signs to the total number of test samples. It varies from 70% to almost 100%. The another aspect is the speed of processing, which largely depends on the database volume and the performed tasks (detection, classification, verification). According to the literature review, many algorithms can work in real-time, which is crucial in practice [1][14].

The literature review shows, that there is no perfect computer vision algorithm. Most of them work with limited databases [1][2][5][6] or are very slow [10][11][12]. Hence we propose a method, which is not influenced by the limited number of signs' classes and the recognition is performed in the real-time.

2. Algorithm description

2.1 Assumptions and theoretical details

The algorithm consists of two stages. The first stage is a learning phase, when the reference feature space is created. All input images are divided into *i* classes.

The preprocessing is as follows. Firstly, all images are normalized, so the scale is constant across all items in the database. In the experiments we used images of 48 x 48 pixels. Then, color RGB images are converted into grayscale. Next, they are normalized in terms of illumination parameters through two-tier method. In the beginning, we map the values in intensity image to new values such that 1% of data is saturated at low and high intensities. This corrects the intensity of the output image. Finally, we perform a histogram equalization, which further increases the contrast. All stages of processing for two exemplary signs have been presented in Fig. 2.

Fig. 2. Two examples of preprocessing stages (in each row): original image, after RGB to gray conversion and intensity adjustment and after histogram equalization, respectively

The next step is related to dimensionality reduction and clustering. We employ well-known Linear Discriminant Analysis (LDA) in its two-dimensional variant (2DLDA) [16], since we want to operate on small covariance matrices. It makes it possible to implement the method on devices installed in cars (embedded systems), because of their relatively low processing power.

The feature space is created on the basis of templates created for typical traffic signs and reduced to low-dimensional representation (typically 5x5 – 10x10 matrices).

The stage related to system operation is related to the actual recognition of a traffic sign (which earlier has been detected and extracted from the scene). Such a traffic sign is normalized according to the approach used at the learning stage and transformed into reduced feature space. The classification is based on the simple distance metrics L_1. We calculate the distance D_i of the test object I to every template (class representative) C_i and select the class i that is the closest one.

2.2 Experimental results

The experiments were performed on a database that was created on a basis of The German Traffic Sign Detection Benchmark [17]. It consists of over color 800 images of outdoor origin presenting signs divided into 43 classes. The signs were photographed in different weather and lighting conditions, from different perspectives and distances. Sometimes they are blurred or skewed. In order to create templates we created mean grayscale images for each class. They are presented in Fig. 3.

In order to imitate the real imaging conditions, when a sign may be occluded by an obstacle (i.e. pole) or covered by snow or dirt, we created a procedure, that modified all test images in such manner, that they were covered by horizontal or vertical bars, as well as noised.

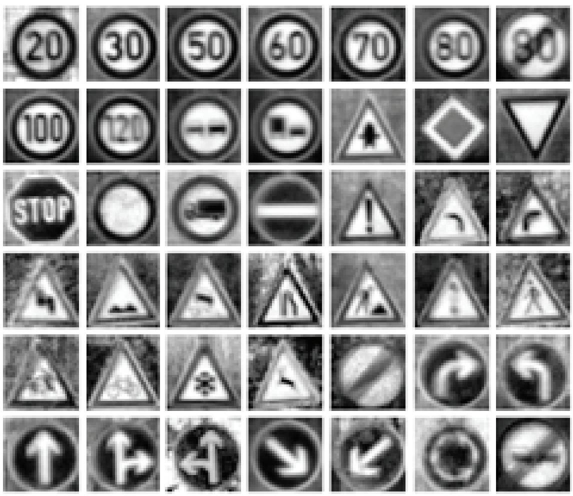

Fig. 3. Templates used for building a reference database

The parameters for the first two modification were the position and the width (height) of the bar. In the third case, the noise was defined by the number of smoothed (by averaging filer) constant pixels added to the original image. The examples of test images are presented in Fig. 4. The first three columns show horizontal occlusion, the second three columns – vertical occlusion, and the last three columns – noising, respectively.

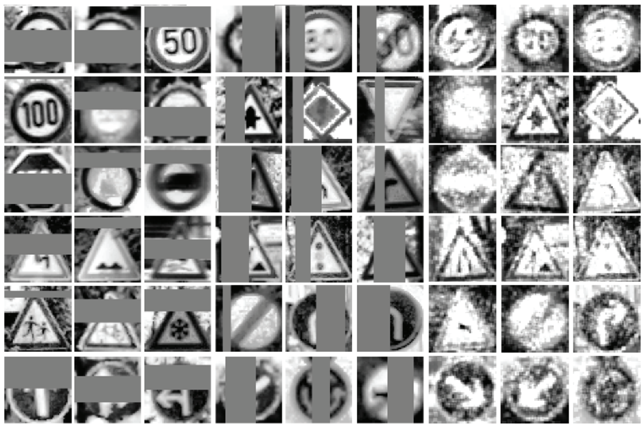

Fig. 4. Exemplary traffic signs used for testing

The results of the experiments related to the dimensionality of feature-space and the area of sign being modified are presented in the following plots.

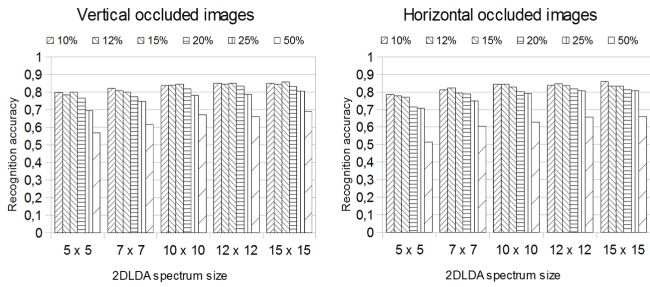

Fig. 5. The results of recognition of vertical and horizontal occlusion for different sizes of 2DLDA spectra (10%, 12% 15%, 20%, 25% and 50% of sign area were covered, respectively)

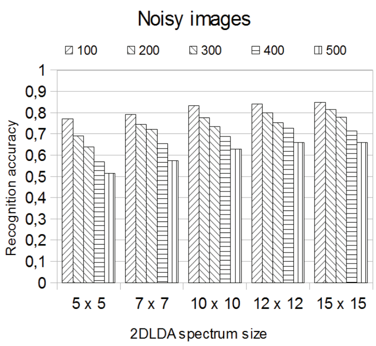

Fig. 6. The results of recognition of noisy images for different sizes of 2DLDA spectra (100, 200, 300, 400 and 500 pixels of sign area were altered, respectively)

As it can be seen, we can obtain the accuracy of 80-85%, which may be acceptable in real-world conditions. Analogous accuracy for not occluded signs is close to 95%. The closer look at the results shows that the optimal size of the feature vector is equal to 10 x 10 elements. Increasing the size of this element do not comes with the significant increase in the recognition accuracy.

The results of recognition are competitive to the ones presented in [12] and [14], yet the processing complexity at the stage of classification is significantly lower.

3. Conclusion

In the article a method of recognizing occluded traffic signs has been proposed. Its main elements are template calculation, lighting correction, dimensionality reduction and distance-based classification. The dimensionality reduction is based on two-dimensional LDA, which eliminates the need of calculating very large covariance matrices (strongly depending on the size of images). Such a feature makes it possible to implement the algorithm in the low processing power devices, such as ones installed in vehicles. The experiments performed on a standard benchmark database revealed that the proposed method is capable of recognize occluded signs, even they are highly distorted. The further research may be devoted to the investigations on recognition of blurred images. The increase in the recognition accuracy may be further obtained by joining the color information in the classification process.

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