Automatic Detection and Recognition of Traffic Signs using Geometric Structure Analysis

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Abstract: This paper proposes detection and recognition algorithm for restricting, warning and information road signs. Sign detection is based on color analysis. In actual, traffic signs have specific color information like red border for warning and restricting signs or blue background for information signs. However in images obtained by camera mounted in the car color information was changed due to lighting and weather conditions such as dark illumination, rainy and foggy weather etc. To solve that problem we use RGB color segmentation with two restriction rules: first rule is bounding constraints for each color component which provides good detection results in images with good lighting condition; second rule is using normalized color information and allows sign detection in dark images. Structure of information signs is differs from structure of warning and restricting signs hence recognition process is also different. The meaning of traffic sign lies in shape of symbols inside of it. Recognition process is based on shape analysis. For warning and restricted signs recognition process consists of two stages. We extract sign candidate from image and classify sign as a circle or triangle using background shape histograms. Then we convert the inner part of sign into binary mask and apply template matching algorithm. To understand the meaning of information sign we separate it into basic components: arrows and text, and then analyze positional relationship between those segments. Detection of arrowheads is based on morphological operations such and analysis of spatial features like area and direction. Result of recognition is name of sign for warning and restricting signs and set of pairs direction - place for information signs.

Keywords: color segmentation, shape recognition, traffic sign recognition, template matching, shape analysis, binarization.

1. INTRODUCTION

Traffic signs provide driver with information important for efficient navigation and safety driving. Hence automated recognition of traffic signs is an important issue for driver assistance systems and autonomous navigation systems. Those systems have to be fast and robust to detect signs in real-time and recognize them precisely. Detection algorithm can be based on color properties of traffic signs. However, color information of input images is sensitive to the change of lighting conditions and weather. Furthermore urban environment contains lots of non-sign objects with shape and color information similar to the traffic signs. It can increase number of sign-candidates and increase recognition time and number of false-positive recognitions – then non-sign object is recognized as a traffic sign. To overcome this problem shape information is used in additional to color properties of sign.

2. SIGN DESCRIPTION

The most essential types of road signs are restricting, warning and information (or guidance) signs. By their properties those signs can be separated into two groups. First group consists of “red-bordered” signs (warning and restricting). Many approaches were developed in recognition of those signs. Some of them are presented in [3,5,7,8]. Second group includes information signs. Recognition of this group is not so well-studied. The reason for that is what information signs are not as well-structured as warning and restricting signs. Different elements and compositions can be used. Division into groups is important because of differences in sign’s structure and hence differences in the processing algorithm.

All signs of the first group have red border. Hence color-based detection algorithm can be applied. Each sign of that group can be disjointed into three parts: red border, white or yellow inner part and black “meaning” part. So, three color groups are presented. That color properties can be useful for sign’s detection and extraction, but the meaning of the sign lies in the shape of black region inside the sign. Hence, recognition part can be based on shape analysis if that part of sign. Main features of restriction and warning signs which are necessary for detection and extraction are shown at Fig.1.

<table>
<thead>
<tr>
<th>Sign type</th>
<th>Possible colors</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>restricting</td>
<td>red + white + black</td>
<td>circle, triangle</td>
</tr>
<tr>
<td>warning</td>
<td>red + yellow + black</td>
<td>triangles</td>
</tr>
</tbody>
</table>

Fig.1. Features of first-group signs.
can be of three colors: green, blue or brown, and symbol information which describes the meaning of the sign. Usually, white color is used to represent information on the sign. Symbol information typically can be separated into three groups: arrow region, text regions with direction descriptions and number region which shows distance to crossroad. Complexity of arrow region can be different depending on real road situation. Key issue in recognition of information sign lies in understanding structure of arrow region. Knowledge about number, position and orientation of arrowheads simplifies separating symbol information into groups by arrow directions. Thus one of important concerning in the algorithm is detecting arrow region. Each arrow region includes at least one arrowhead. Optionally it can also include road numbers. One more possible state is then sign of one color includes sign with background of another color (“sign-in-sign” case). In the proposed framework we assume that all guidance signs have strictly rectangular shape and located vertically. The most important properties are shown in Table 1.

<table>
<thead>
<tr>
<th>Possible background colors</th>
<th>Foreground colors</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>White, blue and red</td>
<td>White text and arrows, blue road numbers</td>
</tr>
<tr>
<td>Blue</td>
<td>White</td>
<td>White text and arrows</td>
</tr>
<tr>
<td>Brown</td>
<td>White</td>
<td>White text and arrows</td>
</tr>
</tbody>
</table>

### 3. SIGN DETECTION

#### 3.1 Detection algorithm

First part of proposed algorithm is sign detection. On this step color and shape properties of signs used to locate candidate regions. Main idea of algorithm detection is shown in Fig. 2.

![Diagram of detection algorithm](image)

Detection algorithm consists of two main parts: candidate detection and filtering. At first step color properties of signs are used in order to detect sign candidates. At second step several constraint rules based on shape properties applying to each candidate in order to eliminate regions that can not be a sign.

#### 3.2 Locating sign candidates

Color segmentation method in RGB color space was used to detect candidate regions. The result of this step is two binary masks (where 0 means background and 1 means possible sign) which represent candidate locations for first and second groups of signs.

To detect first group signs two criteria were used.  

1) First criterion showed good results in good lighting conditions. 

Pixel belongs to red sign if 

\[
(I_{i,j}^r > 50 \text{ and } (I_{i,j}^g - I_{i,j}^b > 15) \text{ and } (I_{i,j}^b - I_{i,j}^g > 15)\]

where \( I_{i,j} \) is pixel of image with coordinates \((i,j)\).

However in bad lighting condition some signs can be missed or detected not clearly (as shown in Fig. 3).

![Example of too dark images](image)

(a) original image; (b) detected candidates (yellow – first criterion; green – second criterion).

2) Second criterion provides stable results in bad lighting condition, but it is too sensitive. In some cases detected regions can be greater than signs.

\[
k = \frac{255}{\max(I_{i,j}^g, I_{i,j}^r, I_{i,j}^b)}
\]

\[
\tilde{I}_{i,j}^r = I_{i,j}^r \cdot k
\]

\[
\tilde{I}_{i,j}^g = I_{i,j}^g \cdot k
\]

\[
\tilde{I}_{i,j}^b = I_{i,j}^b \cdot k
\]

Pixel belongs to red sign if 

\[
(I_{i,j}^r - \tilde{I}_{i,j}^g > 10) \text{ and } (I_{i,j}^b - \tilde{I}_{i,j}^r > 10)
\]

This method provides more robust sign detection even on the dark images (see Fig. 3.).

Examples of detection are shown in Figs. 3~4.
To detect green and blue information signs (brown signs are not considered in this paper) the following criterion was applied:

\[ B_{ji} G_{ji} I_{IM} \max = 4 \] \hspace{1cm} (4)

Pixel belongs to information sign if

\[ R_{ji} R_{ji} I_{IM} > 4.0 \] \hspace{1cm} (5)

3.3 Labeling connected regions

Next step is labeling connecting regions. On this step all connected candidate pixels are grouping as one candidate (using 8-neighbors) if distance in color space between two pixels was less than 30. Bounding box for all candidates was also calculated during this step. After that step we obtain the set of candidates: \( \theta = \{ C^{(1)}, C^{(2)}, ..., C^{(N)} \} \), where \( N \) is number of candidates. Bounding box and area of candidate are also calculated on this step.

3.4 Reducing number of sign candidates

In some cases detection algorithm can find too many candidates (Fig.5.a.). Hence effective method to reduce number of candidates without loosing signs should be used.

In this work the following algorithm was applied:
1. Calculating properties of candidate.
2. Checking rules.

The following constraints were used for the first-group signs. For each candidate \( C^{(i)} \) the following rules were applied:
1. Candidate height > 30 and candidate width > 30
2. Area of sign candidate has to be greater than 30% and less than 80% of corresponding minimum bounding box area.
3. The rate of height and width should be interval of \([0.5, 2]\)
4. Number of black pixels inside the sign should be greater than 0.
5. Number of yellow and white pixels inside the sign should be greater than 0.

That step allows reducing number of candidates from hundreds to tens.

Sample results of detection algorithm are shown in Fig.6.
4. SIGN RECOGNITION

4.1 Recognition of first group signs

Recognition algorithm is different for first and second sign groups. For warning and restricting signs recognition is based on analysis of inner part of sign. Every sign of the first group can be divided into the following parts: border (red), inner part background (white or yellow) and meaningful part (black region inside the sign). Color properties of border were used to detect sign candidate, shape properties to classify candidate as restricted or warning. However to understand the meaning of sign shape of black region has to be analyzed [7]. As far as color has no meaning in that analysis each candidate is represented as a binary mask. Template matching is used to recognize candidate. Recognition scheme is shown in Fig.7.

<table>
<thead>
<tr>
<th>Candidate mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extracting black regions</td>
</tr>
<tr>
<td>Calculating centroid and area</td>
</tr>
<tr>
<td>Template matching</td>
</tr>
<tr>
<td>Sign description</td>
</tr>
</tbody>
</table>

Fig.7. Recognition of first-group signs.

4.2 Shape analysis

First step of recognition is shape analysis. On this step each candidate of first group is classifying as circle or triangle or discarded. Sign class (restricting or warning) is also choosing by that step. Some approaches for shape analysis described at [3,5].

Background shape histograms were used to analyze candidates shape. Each candidate was resized to template size (50x50 pixels) and then its background histogram was obtained. Further difference between candidate’s histogram and template’s histogram (which are presented in Table.1.) was calculated using Eq.(6).

$$E(H^{(i)}, H^{(c)}) = \sum_{i=1}^{N} \left|h^{(i)}_i - h^{(c)}_i \right|^2,$$

where $N$ is number of bins in histogram, $h^{(c)}_i$ and $h^{(i)}_i$ are i-th bins in candidate’s and template’s histogram respectively.

If value of $E$ was less than some predefined threshold, candidate was decided to be circle or triangle (depending on template); otherwise, candidates were discarded.

For the second group candidates that step was not applied.

| Sign | Template database |
|======|-------------------|
| 50   | ![50 sign](image) |
| Triangle | ![triangle sign](image) |

Table 1. Background shape histograms
4.3 Extracting meaning part

Every sign of the first group can be divided into the following parts: border (red), inner part background (white or yellow) and meaningful part (black region inside the sign). Color properties of border were used to detect sign candidate, shape properties - to classify candidate as restricted or warning. But to understand the meaning of sign shape of black region has to be analyzed [5]. As far as color has no meaning in that analysis each candidate can be represented as a binary mask. To extract black regions the following method was applied:

1. Mark all red pixels as 0.
2. If sign is warning – mark all pixels in which \( G > B \times 1.1 \) and \( R > G \times 1.1 \) as 0; otherwise mark all pixels for which \( \min(R, G, B) > (\text{average intensity}) \times 1.3 \) as 0. (Threshold values were selected experimentally)
3. Mark all other pixels as 1.
4. Recursively look through all neighbors of each pixel marked as 1. If the distance in color space is less than some predefined threshold mark pixels as 1.

Result: binary mask \( C^{(i)}_{\text{black}} \cdot C^{(i)}_{\text{white}} = \{0, 1\} \)

4.4 Template matching

Information from shape analyses was used to select template group for matching. Each template mask \( T^{(j)}_{\text{mask}} \cdot j \)-template index) was formed by the following way – value of each pixel was weighted due to number of its nonzero neighbors.

\[
T^{(j)}_{x,y} = \frac{N_{\text{nonzero}}}{8}, \quad \text{where } N_{\text{nonzero}} \text{ is number of nonzero neighbors of pixel at } x,y.
\]

For the more robust results, matching was processed relative to centroid coordinates of template and candidate (Fig.5).

Fig.8. Overlaying using centroid coordinates

Matching problem for candidate \( C^i \) was formalized as follows (see Fig.9.):

\[
\text{matchID} = \arg \left( \min \left( \sum_{x,y} \text{error1}(T^{(j)}, C^{i}) + \text{error2}(T^{(j)}, C^{i}) \right) \right),
\]

where

\[
\text{error1}(T^{(j)}, C^i) = \sum_{x,y \in T^{(j)}} T^{(j)}_{x,y} - \sum_{x,y \in T^{(j)}} C^i_{x,y} \cdot T^{(j)}_{x,y} \tag{7}
\]

\[
\text{error2}(T^{(j)}, C^i) = \sum_{x,y \in T^{(j)}} C^i_{x,y} - \sum_{x,y \in T^{(j)}} T^{(j)}_{x,y} \cdot C^i_{x,y}
\]

Result of this step is identifying number of template which is best matching the candidate.

4.5 Recognition of second-group signs

Some approaches for recognition of information signs shown at [1,2,4,6]. Our algorithm is shown in Fig.10. To understand the meaning of information sign we separate it into basic components: arrows and text, and then analyze positional relationship between those segments. Main part of algorithm is candidate segmentation. On this step structure of sign was extracted and analyzed in order to distinguish symbolic information (arrows, road numbers, etc) from text.

Fig.9. Calculating matching error.

Fig.10. Recognition of information signs

5. EXPERIMENTAL RESULTS

Real images were used for experiments. Images were taken in different lighting and weather conditions in order to analyze robustness of proposed algorithm. Results of detection step are presented in Tables 2–3.

<table>
<thead>
<tr>
<th></th>
<th>Warning and restricting signs</th>
<th>Information signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of images</td>
<td>124</td>
<td>95</td>
</tr>
<tr>
<td>Number of signs</td>
<td>172</td>
<td>119</td>
</tr>
<tr>
<td>Not detected</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>(2.3%)</td>
<td>(0.8%)</td>
<td></td>
</tr>
<tr>
<td>Table 3. Recognition results for first-group signs.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of images</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>Number of signs</td>
<td>172</td>
<td></td>
</tr>
<tr>
<td>Not recognized</td>
<td>11 (6.4%)</td>
<td></td>
</tr>
<tr>
<td>False-positive recognition</td>
<td>4 (2.3%)</td>
<td></td>
</tr>
</tbody>
</table>

All experiments were done on Pentium-IV 2.6 with 512MB RAM under Borland Builder 6.0 environment. Images of size 640x480 were used. Computation time was measured by means of C++ to hundreds of second. Results are presented in Table 4.

<table>
<thead>
<tr>
<th>Table 4. Average computation time.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
</tr>
<tr>
<td>-----------------------------------</td>
</tr>
<tr>
<td>Detection</td>
</tr>
<tr>
<td>First-group signs recognition</td>
</tr>
<tr>
<td>Information signs recognition</td>
</tr>
</tbody>
</table>

6. CONCLUSIONS

Experimental results indicate that the proposed method can be used for real-time detection and recognition of restricting, warning and information signs. The proposed system shows good recognition rate for various lighting and weather conditions. It provides robust results in dark and rainy environment. Nevertheless our system can be improved to decrease number of false-positive detections for reducing total computation time.

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