Triangular Road Signs Detection and Recognition Algorithm and its Embedded System Implementation

Ting Chou, Ssu-Yuan Chang, Vinay M.S. and Jiun-In Guo
Department of Electronics Engineering, National Chiao Tung University, Hsinchu, Taiwan, R.O.C.

Abstract—This paper proposes a low-complex triangular road signs detection and recognition algorithm that can be implemented on an embedded system for real-time applications and maintains decent detection and recognition accuracy under inclement weather conditions. The proposed method is composed of the shape detection to locate triangular road signs followed by the two feature extraction methods to focus on their different contents, and the descriptor construction method to eliminate the noise and make the system robust. This work is implemented on a desktop computer as well on an automotive-grade Freescale i.MX 6 embedded platform. Under a video resolution of 1280x720, the proposed system achieves 161 fps on the desktop computer and 17 fps on the Freescale i.MX6 embedded platform with an overall accuracy of 93.33%.

Index Terms—Advanced Driver Assistance System (ADAS), Shape detection, Triangular road signs, Feature Matching

I. INTRODUCTION

With the advancements in the vehicular designs and increase in the traffic worldwide over the last decade, the car camcorders have become more and more popular. The intelligent systems such as lane departure warning systems, forward collision warning systems, driver drowsiness and behavioral detection systems collectively referred as Advanced Driving Assistance Systems (ADAS) have increased the safety of the drivers as well as of the pedestrians.

With camcorders in place, the footages of traffic accidents, reckless driving and other on-road and road-side incidents can be recorded. The recorded videos can be the evidences for legal actions in case of any fatalities. On the other hand, the camcorders can also be used to capture the road signs and thus used for their detections and recognitions. We have developed a low complex algorithm to detect, recognize speed related or regulatory triangular road signs in different countries and to implement on the embedded platforms for real-time applications thereby assisting the drivers. In this paper, an attempt is made to reduce the complexity of algorithms, template databases and computing resources by using car camcorders efficiently and combining them with ADAS functions together on a single embedded platform.

Currently, color-based algorithms are being vastly adopted for road signs detection and recognition along with the trained dataset for template matching in the recognition phase using machine learning algorithms. This approach need to collect training samples based on different cameras, resolutions, inclinations, intensities and so on. Hence it takes long period of time to make it less practical. Furthermore, color-based algorithms could have bad accuracy due to lighting changes.

II. BACKGROUND

A. Road Sign Detection

The main objective of the road sign detection step is to select the potential candidates by locating them from their appearance in the real environment. In this paper, the triangular road signs related to speed regulation as in Fig.2 are detected. As a result, the shaped-based approaches in this application focus on detection of the triangular shaped road signs.

Therefore, this paper proposes a low complex algorithm comprising shape detection to locate the road signs followed by the two feature extraction methods and a descriptor to recognize contents of the triangular road signs. The implementation shows that the proposed algorithm can be realized in the automotive-grade i.MX6 platform at 1280x720 achieving 17fps for real-time processing demands.

The rest of this paper is organized as follows: Section II makes a brief survey on the existing road signs detection and recognition techniques. Section III illustrates the proposed algorithm. The experimental results of the proposed algorithm are discussed in the Section IV. Finally, the conclusion is included in Section V.
There are several algorithms for shape detection in the probable sign location process, such as radial symmetric transform [1][2], Hough Transform [3][4][5], and some other methods like VBT [6]. These methods have their own trade-off between computational cost and accuracy.

B. Road Sign Recognition

In the road sign recognition, we classify the road signs, that is, to recognize the actual content in the signs. There are many algorithms proposed to do this in the computer vision, such as image feature detection, template matching, and machine learning-based approaches.

There are many methods of image feature detection, like FAST[7], which can extract feature rapidly while having high repeatability. In addition, there are different kinds of descriptors like SIFT[8], SURF[9], binary descriptors like BRIEF[10], ORB[11], BRISK[12], and FREAK[13]. A clear advantage of binary descriptors is that they claim to be low computational cost algorithms with competitive accuracy.

III. PROPOSED ALGORITHM

The proposed algorithm for detection and recognition of the triangular speed regulatory road signs is composed of four parts as shown in Fig. 3. They are triangle detection for locating the potential triangular road signs, Features from Accelerated Segment Test (FAST) for feature extraction, Fixed Feature Extraction is applied to extract the information of the road signs with simple and complex contents. The final step is feature matching that uses the BRIEF descriptors to describe the extracted features and matching them with the descriptors in the database.

A. Shape Detection

The voting process is based on the gradient of each pixel [14]. The vote generated from each pixel follows the rule of the proposed triangle detection algorithm shown in Fig. 4. First, we apply Sobel operator to calculate gradient for each pixel. Sobel operator is a differentiation operator which is implemented by a Sobel mask. Consequently, we calculate the horizontal and vertical gradients by convolving the corresponding Sobel masks. Each selected pixel is represented with its absolute magnitude, and the gradient vector is denoted as \( \mathbf{g}(p) \). The direction of \( \mathbf{g}(p) \) can be formulated with the horizontal gradient \( \mathbf{G}_x \) and the vertical gradient \( \mathbf{G}_y \) into an angle as shown in Eq. 1. Only 180 degrees of gradient is used in this algorithm followed by the morphological erosion to eliminate noises.

\[
\mathbf{g}(p) = \tan^{-1} \frac{\mathbf{G}_y}{\mathbf{G}_x} \quad (1)
\]

Next, as shown in Fig. 4(a), the proposed algorithm exploits the nature of triangle for detection. We look for the points which have a gradient of 30 degree, defined as point A. Once the point A is obtained, we search for the points that have a gradient of 150 degrees on the same row as that of point A, defined as point B. The last step is to find the points C and D with 90 degrees gradient on the same column with point A and point B, respectively. Once all these points are determined, a vote is placed to the point G at the center of the triangle as in Fig. 4(b).

![Fig. 4. (a) Illustration of triangle detection algorithm (b) Illustration of voting for the center](image)

In order to vote for the center point, the width of the detected position and the size of the target triangle is required to be calculated. The formulae shown in Eq.2, where \( \text{Center}_x \) is the x coordinate of G, \( \text{Center}_y \) is the y coordinate of G, H is the height of the small triangle, and D is the size of the target triangle, as shown in Fig. 4(b).

\[
\begin{align*}
\text{Center}_x &= \frac{A_x + B_x}{2} \\
H &= (B_x - A_x) \times \frac{\sqrt{3}}{2} \\
\text{Center}_y &= \begin{cases} 
A_y + D \times \frac{\sqrt{3}}{3}, & H \leq D \times \frac{\sqrt{3}}{2} \\
A_y + H - D \times \frac{\sqrt{3}}{3}, & H > D \times \frac{\sqrt{3}}{2}
\end{cases}
\end{align*}
\quad (2)
\]

Then the width of the detected position is needed for calculating the detected points A and B. Thus, it is easy to build
a look up table to reduce the computation cost of the voting process. After this, the positions that have higher votes are supposed to be near the center of the triangular road sign candidates. In order to reduce the computation cost, candidates that are close to each other will be merged to one candidate. The new coordinate of the candidate is the weighted arithmetic mean calculated using the coordinates of the merged candidates weighted by their votes. This is a simple method to reduce some different candidates that represent the same triangle.

B. FAST feature extraction

FAST[6] is a high repeatability corner detector named Features from Accelerated Segment Test. As shown in Fig. 5, it uses a circle of 16 pixels to classify whether or not a candidate point p is a corner. Furthermore, the detecting algorithm can be improved by machine learning and accelerated by high-speed test.

The FAST feature extraction conditions can be written as in Eq.3.

\[(a) \quad \forall x \in S, I_x > I_p + t \]
\[\quad \forall x \in S, I_x < I_p - t \]  \hspace{1cm} (3)

where S is a set of N contiguous pixels in the circle, \(I_x\) is intensity of \(x\), \(I_p\) is intensity of candidate \(p\) and \(t\) is the threshold.

There are two parameters to be chosen in FAST algorithm namely, the number of contiguous pixels \(N\) and the threshold \(t\). \(N\) is fixed as 9 in the proposed algorithm. In order to overcome the changes in the intensity inclinations as shown in Fig. 6, the threshold \(t\) is set to be dynamic. The dynamic threshold is calculated by the image patch of the sign candidates. First, we count for pixels with intensity bigger than 128. If the number of bright pixels is between 20% and 80% of the total number of pixels in the image patch, the threshold is computed by the percentage of number of bright pixels over the total number of pixels. There are two fixed thresholds for the conditions that the number of bright pixels is lower than 20% of the total number of pixels or higher than 80% of the total number of pixels. Accordingly, the threshold dynamically updates to the number of bright pixels over the total number of pixels.

C. Fixed Feature Extraction

There are certain conditions due to which the contents of road signs are too simple to be extracted using the FAST feature, as shown in Fig. 7. Thus, the Fixed Feature Extraction is applied to handle these road signs with good inclinations in the proposed algorithm.

Fixed Feature Extraction uses thirty fixed feature points to describe a road sign, as shown in Fig. 8. This method is similar to template matching, but it is more robust to noises as it uses descriptors to describe the small area around the feature points.

D. Feature Matching

The main objective of this phase is to match the features between the pre-built template and the detected sign candidates as shown in Fig. 9. The features extracted previously are matched by their coordinates and the descriptors which are constructed to describe features. Due to the fact that the proposed system is aimed at real-time applications, the construction and the matching procedure of the descriptor algorithm should be both simple and efficient.

Binary Robust Independent Elementary Features (BRIEF)[9] is a simple descriptor with good matching
performance and low computation cost. In order to build a BRIEF descriptor of length n, we need to decide n pairs \((x_i, y_j)\). X and Y are randomly sampled with Gaussian distribution and stored in a pre-built array to reduce computation cost. To build a BRIEF descriptor, the test is defined as in Eq. 4 and n is chosen as 256 to yield the best performance.

\[
\tau(p; x, y) = \begin{cases} 
1 & p(x) < p(y) \\
0 & p(x) \geq p(y)
\end{cases}
\] (4)

Fig. 9. Steps followed in the Feature Matching

The advantages of BRIEF are obviously, low computation time and good matching performance whereas the disadvantage is that the BRIEF is not rotation invariant and scale invariant. Since the size of the detected signs is fixed and the road signs would not have too much rotation effect, these disadvantages do not influence the recognition result.

After descriptor construction, a two-step matching process comprising distance matching and descriptor matching is applied to match the detected sign candidates with the pre-built templates. Distance matching considers only the coordinates of the feature points. In this application of road signs recognition, the detected road signs should be a regular triangle with some defects such as, lighting changes, slight rotation, occluded with an object. Thus, the two similar feature points are not matched if the coordinates of these two feature points are different.

The goal of descriptor matching is to compute the distance between two descriptors, one is from the detected sign candidate and the other is from the pre-built template. As with all the binary descriptors, the measure of BRIEF distance is the number of different bits between two binary strings which can also be computed as the sum of the XOR operation between the strings.

After all sign candidates are matched, the scores comparison is applied to choose which template is the most suitable for final recognition result. The template with the score higher than the others become the final result of the template matching. Moreover, the same result should be recognized a few times in several frames of a video to make sure that the result does not produce a false alarm.

IV. EXPERIMENTAL RESULTS

The proposed algorithm is implemented in C on the desktop computer as well on the Freescale i.MX 6. Freescale i.MX6 is an automotive-grade standard developing processors for the real-time vehicular applications. The Freescale i.MX 6 series of applications processors is a feature and performance scalable multicore platform that includes single, dual and quad-core families based on the ARM® Cortex® architecture, including Cortex-A9, combining Cortex-A9 + Cortex-M4 and Cortex-A7 based solutions. When the algorithm is executed, the videos consisting of triangular signs or the images captured from the webcam are used as real-time inputs. The results of the proposed method are shown on a display connected to the i.MX6 board.

Table 1 and Table 2 shows the specifications of desktop computer and i.MX6 platform, respectively.

<table>
<thead>
<tr>
<th>CPU</th>
<th>Intel® Core™ i7-4790 CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>3.6GHz</td>
</tr>
<tr>
<td>Memory</td>
<td>8GB</td>
</tr>
<tr>
<td>OS</td>
<td>Ubuntu 14.04</td>
</tr>
</tbody>
</table>

TABLE 2. The specification of Freescale i.MX 6

<table>
<thead>
<tr>
<th>CPU</th>
<th>ARM Cortex-A9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>1GHz</td>
</tr>
<tr>
<td>Memory</td>
<td>1GB</td>
</tr>
<tr>
<td>OS</td>
<td>Linux</td>
</tr>
<tr>
<td>VPU (Video Processing Unit)</td>
<td>Decoder: H.264, MPEG-4, H.263, MJPEG Encoder: H.264, MPEG-4, H.263, MJPEG</td>
</tr>
<tr>
<td>IPU (Image Processing Unit)</td>
<td>Blending, rotating, scaling, cropping, de-interlacing, color spacing converting</td>
</tr>
</tbody>
</table>
On the desktop computer, the image resolution is set as 1280x720 and the performance can reach 161 fps on an average. On Freescale i.MX 6, the image resolution is also set as 1280x720 and the performance of the proposed algorithm is 17 fps. The accuracy of the proposed algorithm is over 93% and the performance details are listed in Table 3.

The proposed algorithm is a real-time executing algorithm and is robust in different weather conditions such as sunny, backlight, cloudy and night.

<table>
<thead>
<tr>
<th>Video resolution</th>
<th>Triangular Road Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total video frames count</td>
<td>227445</td>
</tr>
<tr>
<td>Total road signs count</td>
<td>60</td>
</tr>
<tr>
<td>Detected signs</td>
<td>59</td>
</tr>
<tr>
<td>Detection Accuracy</td>
<td>98.33%</td>
</tr>
<tr>
<td>Total correctly recognized signs count</td>
<td>56</td>
</tr>
<tr>
<td>Recognition Accuracy</td>
<td>94.49%</td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td>93.33%</td>
</tr>
</tbody>
</table>

The proposed algorithm is compared with some of the previous works. As listed in Table 4, the proposed design provides high accuracy and competitive performance in the application of triangular speed regulatory road signs detection and recognition. It can achieve real-time implementation on an embedded systems due to the low computation cost of the algorithm supporting the detection and recognition of different speed related road signs in Europe.

TABLE 4. The comparisons of other works and the proposed design

<table>
<thead>
<tr>
<th>[13]</th>
<th>[14]</th>
<th>[15]</th>
<th>[16]</th>
<th>[17]</th>
<th>Proposed Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>Intel Core i3</td>
<td>Pentium-IV 2.6 GHz</td>
<td>Intel Core i7</td>
<td>X</td>
<td>Tesla K20 GPU platform</td>
</tr>
<tr>
<td>Video Resolution</td>
<td>X</td>
<td>640x480</td>
<td>1280x960</td>
<td>640x480</td>
<td>1628x1286</td>
</tr>
<tr>
<td>Frame Rate</td>
<td>0.5 fps</td>
<td>11.1 fps</td>
<td>33 fps</td>
<td>13.5 fps</td>
<td>27.9 fps</td>
</tr>
<tr>
<td>Detection Accuracy</td>
<td>98.25%</td>
<td>97.7%</td>
<td>95.87%</td>
<td>96%</td>
<td>91.69%</td>
</tr>
<tr>
<td>Recognition Accuracy</td>
<td>84.3%</td>
<td>93.6%</td>
<td>99.16%</td>
<td>96.08%</td>
<td>93.77%</td>
</tr>
<tr>
<td>Overall Accuracy</td>
<td>82.82%</td>
<td>91.44%</td>
<td>95.07%</td>
<td>92.23%</td>
<td>85.97%</td>
</tr>
<tr>
<td>Sensor Required</td>
<td>Vision</td>
<td>Vision</td>
<td>LiDAR + Vision</td>
<td>Vision</td>
<td>Vision</td>
</tr>
</tbody>
</table>

Fig. 10. The target speed related road signs in Europe and Fig. 11 shows some of the experiment results of the proposed algorithm under different conditions.

**Fig. 10. The target speed related road signs in Europe [16][17]**

**Fig. 11. The results of speed related road signs detection under different light conditions (a) during day time (b) during the backlight condition (c) during the cloudy weather (d) during the night time**
V. CONCLUSIONS

In this paper, we have proposed an efficient triangular speed regulatory road signs detection and recognition algorithm. It works efficiently under different weather conditions with good accuracy, and also maintains decent performance rate for the real-time applications. The proposed design can extend the functions of car camcorders to detect triangular road signs, to actively ensure the safety of drivers.

With the increasing demands to ensure the safe driving, the future work of the proposed design will aim at wide range of traffic signs of different shapes supporting the autonomous driving vehicles.

REFERENCES