Traffic Signs Shape Recognition Based on Contour Descriptor Analysis

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***Abstract*— Methods for automated traffic sign detection and recognition represents one of many structural pillars and basic building blocks in autonomous and self-aware transportation systems. Computationally efficient and recognition successful methods have great importance in accomplishments of such tasks. This paper presents a novel technique for traffic signs shape recognition that is based on analysis of the signs shape contour descriptors. The primary task of the presented method is proper recognition and classification of signs by their shapes into three basic categories; circle, triangle and square/rectangle one. The method utilizes a shape contour description in the manner of absolute angular tracing characteristics of a sign shape. Contour descriptors of different sign shapes in various imaging condition are analyzed, results are shown and evaluated. The presented method successfully distinct traffic signs by their shapes and proves the method usability.**

Keywords— contour descriptor; shape recognition; traffic signs detection

I. Introduction

Traffic signs detection and recognition have an important role in today's way of living. They represent one of many methods for traffic regulation that heavily relies on human sight and visual perception. Due to the simplicity of information spreading, based on 2D visual perception and easiness to understand, the traffic signs will be the main tool for on-road informing for a long time. Today, besides traffic signs, there are systems that are a supplement to traffic signs, but they are more complicated and often need additional power from other energy sources that may not be available on every site or road. Populated areas intrinsically coincide with dense traffic. There are many efforts to develop self-driving solutions as a transportation tool that excludes a man from driving process. Google made a great leap in that direction but, there are other research groups, like [1], with similar results. Besides autonomous driving, classification and recognition of traffic signs have great importance in application of assisted driving. As a driving assistance, the traffic sign recognition has role on diminishing human errors in the driving process by eliminating traffic signs misperception or misinterpretation. The main precondition to achieve autonomous or assisted driving is efficient traffic sign detection, classification and recognition consecutively. There are many methods and research programs devoted to the machined perception of traffic signs with more or less success. All analysis methods can be divided into three focusing areas; signs detection, signs shape recognition and signs classification. In [2], the authors are focused on developing driver alert system by applying the sign shape analysis based on corner detector and fast radial symmetry methods. Also, a fast contour feature analysis method used in [3] is suitable for real-time processing. A general survey of contour description methods and their features that are used in general shape description are given in [4]. Some often used techniques for traffic sign detection and segmentation out of analyzed scenes are presented in [5-7]. These methods heavily rely on color separation techniques to distinct a traffic sign from a scene background. As a final step in the analysis, a proper traffic sign classification is needed for a successful traffic sign detection and classification. In [8, 9], neural networks are used as a lately popular and efficient method for classification. Neural networks achieve good results in classification, especially in harsh imaging condition and they can easily accommodate changing requirements. Furthermore, except the methods punctuality and reliability, the ability to perform analysis in real-time is crucial. Real-time characteristic is mandatory when the systems become "alive" and serve their purpose. In [3, 10] is presented one of the systems that complies with real-time requirements and asserts problems related to time-strict analysis. Achieving a real-time characteristic, especially in image analysis, is not an easy task and requires powerful computers and efficient analysis methods.

This paper presents a method that is shape-analysis oriented in the manner to perform an efficient distinction of traffic signs by its shape. Good shape recognition allows an efficient post-analysis related to traffic signs classification. This method is based on the method presented in [11] where a shape contour descriptor analysis is successfully used to describe ceramic tile geometrical features with addition of finding edge and corner defects. Contour descriptor used in this paper, represents a novel method for the traffic sign shape description. As a result, this method gives shapely unique absolute angular tracing descriptor which is the main distinction feature for successful shape recognition.

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Article paper is organized in the following sections: in section II, the traffic sign detection and segmentation technique is explained. This technique relies on color separation approach. In section III, theoretical description of the contour descriptor method is described and applied to three basic shapes in traffic signs. In section IV, the experiment is conducted in the manner to apply contour description techniques on traffic signs taken from real situations. Also, the comparison of sign descriptors is done and the results are elaborated on.

II. Traffic Signs Detection

Finding a traffic sign in the picture is not easy because there is a lot of information. To avoid misperception and enhance visibility and noticeability, traffic signs are colored in a fashion that combines bright and vivid colors whose combination appearance would not be expected in nature by coincidence. Since their colors are bright and noticeable, traffic signs can be detected and located by analyzing color information of objects in the analyzed image. However, some noise might appear depending on the method which is used, luminance, in which period of the day is the photo taken etc. Due to their specific color properties, signs are often detected and localized by using color separation and segmentation techniques. There are a few such methods like transforming an image to HSV color space [2, 3] or HSI [6], applying a hybrid color space based procedure like [5] or RGB segmentation. Mutual property of these methods is object detection and separation due to its color accent toward the scene background. In this paper, the chromatic separation approach was used.

A. Chromatic Separation Approach

In order to find and analyze an object in a scene and to exclude noise, it is advisable to use the chromatic separation approach and color description models such as HSV (Hue, Saturation and Value), HSI (Hue, Saturation and Intensity) or HSL (Hue, Saturation and Lightness). The use of such color description model suits better for chromatic separation purposes because it is closer to the human way of color perception and thus more intuitive for further method development than, for example, RGB one. An HSV color wheel can be seen as a cone or a cylinder in a color description model space. Hue is described as a number from 0 to 360 which represents hues of red, yellow, green, cyan, blue and magenta i.e. colors in their purest form. Saturation is the amount of gray in the image. It shows the dominance of hue in the color. The value describes the brightness of the color. Depending on the purpose of using HSV method, intervals of hue, saturation and value are used to distinct or emphasize a part of the image that contains specified HSV properties. If the analyzed pixel of the image meets (are within) the defined HSV selection conditions (intervals), that part of the image is useful and can be marked to set apart from the background.

B. Detection of Traffic Signs in Static Images

Traffic signs are invented to remind the drivers for possible speed limitations, restrictions, dangers on the road, etc. They are designed to be noticeable with their shape and bright colors that stand out from the background. Because of that bright color, a traffic sign can be extracted from the background using chromatic separation, more specifically and used in this paper, an HSV method. The vast majority of traffic signs is multicolored and very few of them are mono-colored. For the detection purposes, only external/perimeter color is needed and used for further segmentation and analysis steps. Signs that have different coloring patterns and structures inside are not important for the successful sign classification by its shape. Depending on what color needs to be extracted (red for danger, warning signs and signs of prohibition, blue for information signs, etc.), interval for hue, saturation and value are set and only objects which are within the defined interval, stay in the image. Intrinsically, the problem is how to properly define and set those intervals of HSV filtering because they strongly depend on the brightness, clearance, resolution, luminance of the environment in a picture, etc. In this paper the HSV filtering intervals are defined experimentally (and manually) for optimal detection results. The exact values of the filtering intervals are not given in this section, mainly because of their diversity and changeability regarded to analytic scene configurations.

III. Traffic Signs Classification

Generally, there are four basic types of traffic signs:

- Danger and warning,
- prohibitory,
- information and
- others.

For classifying traffic signs, fast radio symmetry method and Harris corner detection algorithm are successfully used in [2], basic matching feature tables are made for comparison and identifying candidate regions in [3], neural networks are used and tested in [6] and [10]. There are two classes of approach in shape description: contour-based and region-based. Contour based are more popular, but generally sensitive to noise and variation. In [11] a contour descriptor method is proposed and successfully used to identify failures on ceramic tile edges and shape related deviations. That method represents the keystone for detection and classification of traffic signs in this paper.

A. Contour Descriptor

A contour description method, presented in [11], is a novel shape tracing and a shape description method that integrates tracing and description procedure into a unity. This method performs contour tracing and shape description simultaneously onto the filtered binary image which is a result of HSV color separation. The result of this method is a 2D graph (called contour descriptor) of shape absolute tracing angle changes (vector of tracing angles) and is a result of directional searching method propositions. A detailed description and properties of the method are given in [11]. Brief and most important key facts about this method follow. The contour description procedure consists of two parts;

- Finding shape edge contour pixels and
- tracing edge contour pixels with predefined angle of searching direction, φ, and marking it down.

For tracing edge contour, two parameters are needed. First is searching direction angle of the previous pixel and the second is searching coordinates of a next pixel. For finding the next pixel, a matrix *S(k)* needs to be calculated, (1)

$$S(k)=S(k-1)+D(k),\ k\in[1\ldots l] \qquad (1)$$

where $S(0)=0$ and $\varphi(0)\in(0\ldots 2\pi)$ which strongly depends on shape type and method for finding entry point (here is used horizontal scanning for 1st pixel), l is shape contour length in pixels. The *S(k-1)* is searching direction angle of the previous pixel and *D(k)* is a matrix with predefined and calculated searching direction, given in (2).

$$D(k)=\begin{bmatrix} \cos(\varphi_{k-1}) & \sin(\varphi_{k-1}) \\ \cos\left(\varphi_{k-1}+\frac{\pi}{4}\right) & \sin\left(\varphi_{k-1}+\frac{\pi}{4}\right) \\ \cos\left(\varphi_{k-1}-\frac{\pi}{4}\right) & \sin\left(\varphi_{k-1}-\frac{\pi}{4}\right) \\ \cos\left(\varphi_{k-1}+\frac{\pi}{2}\right) & \sin\left(\varphi_{k-1}+\frac{\pi}{2}\right) \\ \cos\left(\varphi_{k-1}-\frac{\pi}{2}\right) & \sin\left(\varphi_{k-1}-\frac{\pi}{2}\right) \end{bmatrix} \qquad (2)$$

The most preferred direction is the first row of matrix *D(k)*, then comes second row, third, fourth and the fifth row, as Table I shows.

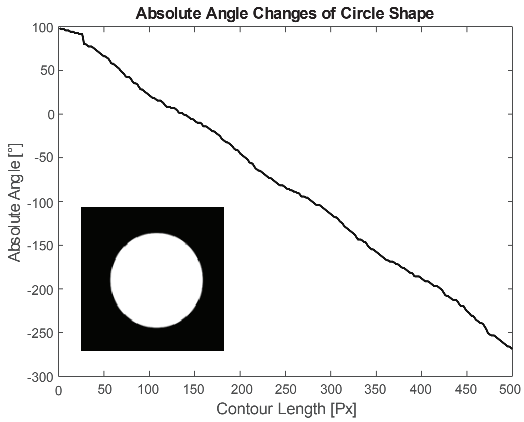
TABLE I. TRACING DIRECTIONAL PRIORITIES ORDER

Trace Direction [rad / °]	**Priority Weight [0…4]**	**Tracing Order**
0 / 0°	0 – Highest	First
π/4 / 45°	1 – Higher	Second
-π/4 / -45°	2 – Middle	Third
π/2 / 90°	3 – Lower	Fourth
-π/2 / -90°	4 – Lowest	Fifth

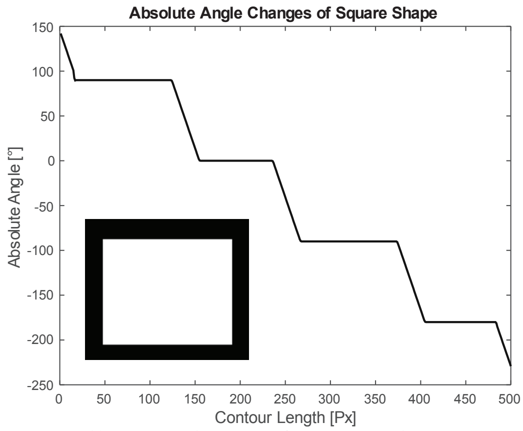
The algorithm for searching directions stops when it reaches the first found pixel, if it is close to the first pixel or if there is not any neighbor pixel. The problem might occur if the shape contour is not closed, so it is advisable to use some method for checking the continuity of the contour and filling the gaps if needed.

B. Traffic Signs Shape Description and Contour Descriptors

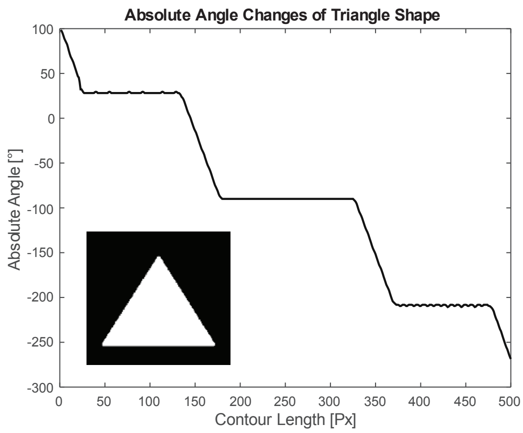
The application of the contour descriptor method onto three basic shapes in traffic signs palette results with a distinctive contour descriptor for these shapes. *Contour descriptors* are vectors of absolute angular changes during the shape contour tracing as the method proposes. Based on the graph of absolute angle changes, the shape of the traffic sign can be visually distinct. All of these shapes have clearly different contour descriptors with strongly accented corners, straight segments (edges), curved edges, etc. The tracing length of the specific contour descriptor's segment is directly related to the analyzed shape size and linearly rises with the size of the analyzed shape. In Fig. 1a, 1b and 1c, contour descriptors are shown (absolute angle change vectors) for three basic traffic sign shapes according to their contour tracing length (in pixels and normalized to 500 for demonstration purposes); circle shaped (prohibitory signs), triangle shaped (warning and danger signs) and squared/rectangle shaped (information signs). These contour descriptors are later used as reference descriptors for shape comparison and recognition. Every shape has its unique and distinctive graph and can be easily categorized in groups (triangle, circle or square). The circle shape characterizes a constant angular change that is similar to a line structure without sudden drops or rises or any other contour changes.



a) Contour descriptor for a circle shape.



b) Contour descriptor for a square shape.



c) Contour descriptor for a triangle shape.

Fig. 1. Contour descriptor for three basic types of sign shape.

On the other hand, rectangle and triangle signs have similar contour descriptors, but different in some contour features. Both are stair-like structure, but with a different number of steps (each step represents a corner of a shape) and stair step slope (a slope represents the presence of rounded edges/corners). Because of the simplicity, the contour descriptor method is a computationally very efficient method. Therefore, the whole tracing procedure can be done in a fashion of real-time execution. On the other hand, by knowing the shape of the traffic sign, post analysis time for searching right sign in signs database is at best triple-fold reduced, which makes the whole process of finding and classifying traffic sign significantly shorter.

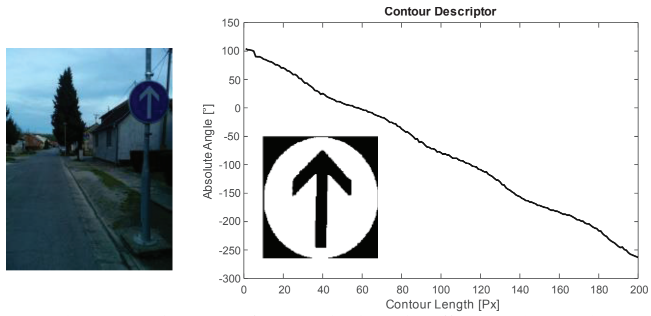
IV. Experimental Results

A. Test Setup

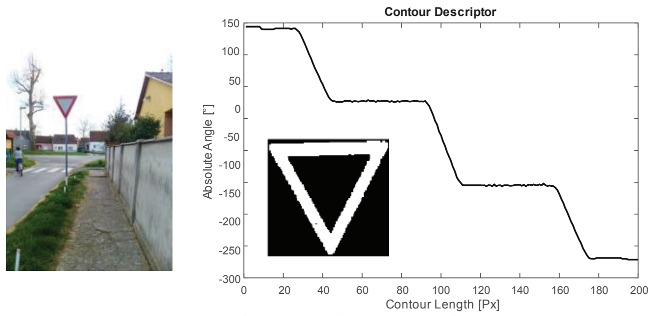
The application of the method and tests are performed only under MATLAB development environment (Intel Core i3-2350M@2.30 GHz, 4GB DDR3, Windows 10 64-bit, nVidia GT525M) and on photographs (1280x960px) taken from the real-scene environments. The tests are conducted on the triangle, circle and square/rectangle shaped traffic signs. They are done off-line on several signs scene configurations. Scene configuration includes the captured traffic sign in a real situation, different by distances and projections (distortion of shapes according to signs analysis spatial vicinity). The scenes actually includes only two cases per sign in order to show the results of extremes. The graph of absolute angle changes will be analyzed and qualitatively compared. The focus of this article is not to determine exact and quantitative measure nor development of the comparison cost functions, but to demonstrate the potential of the method through visual comparison of analyzed shape descriptors. Computational times are specifically related to the given computer platform configuration and can be significantly different or improved on other configurations.

B. Results and Analysis

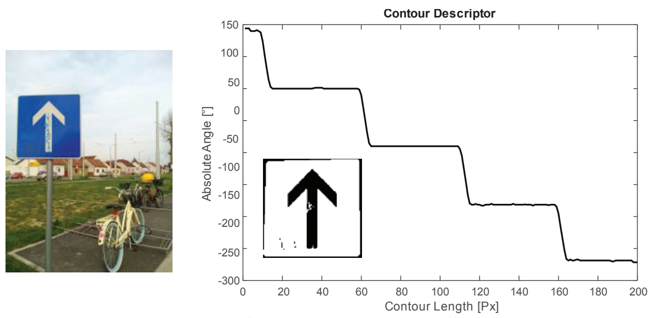
The presented method is applied onto three real situations where one prohibitory, one warning and one information sign are analyzed. Fig. 2a, 2b, and 2c shows a real scene with a presence of traffic signs and resulting contour descriptors for each sign in given scene (processing times represent the whole operation time needed, capturing excluded). Due to the difference in the contour length of the shapes, all contour descriptors are normalized to the length of 200 pixels (as normalization length is a user choice, the intention of selecting different normalization length is to show the similarity of the descriptors of the same shapes in Fig.1 and the rest of the figures). Normalization of contour lengths helps in the contour comparison process. By direct contour comparisons (for example, determining minima of the descriptors elementwise difference cumulative sum can be one of approaches for comparison) a quantitative measure of distinction can be made. As is similarly stated for Fig. 1a to 1c, these shapes differ significantly by their contour descriptors and descriptor features. Computational times differs significantly and greatly depends on the vicinity of the sign and sizes of analysis segments. Fig. 3 directly shows the comparison difference of all descriptors. Because of their descriptor differences, it is simple to visually notice which contour descriptor is for which shape. Circle shape has a descriptor that is smooth and without significant change in the angle changes. Triangle and rectangle shape differs in a number of steps which is the result of a different number of the straight portion of their shapes. Furthermore, if the method detects a circle shape, there is no need to search for content of analyzed traffic sign among triangle or rectangle signs.



a) Contour descriptor for a circle shaped traffic sign, (t=0.87s).



b) Contour descriptor for a triangle shaped traffic sign, (t=0.85s).



c) Contour descriptor for a square shaped traffic sign, (t=1.67s).

Fig. 2. Traffic sign recognition and contour descriptor.

Afterward, the time needed for searching the right traffic sign in the database is reduced significantly and the shape recognition and classification method proves its usability in the manner of computing efficiency and suitability for real-time computing. Fig. 2 and 3 depict the results of the analysis on signs that are relatively shapely consistent. It means that shapes of signs are almost pure triangle, circle, and rectangle. In practice, that is not always a real situation. As the camera moves toward a traffic sign, the sign changes its shape due to the projection distortion. A sign shape distorts more as the spatial vicinity of a sign to the camera is reduced or becomes smaller. The biggest distortion of a traffic sign is in the scenario when the sign is on periphery of an acquired image, close vicinity respectively (only that cases are used for descriptor comparisons regarded to referent one). How does the method describe such distorted traffic signs and how does it interpret? The results of such analysis are shown in Fig. 4a to 4d.

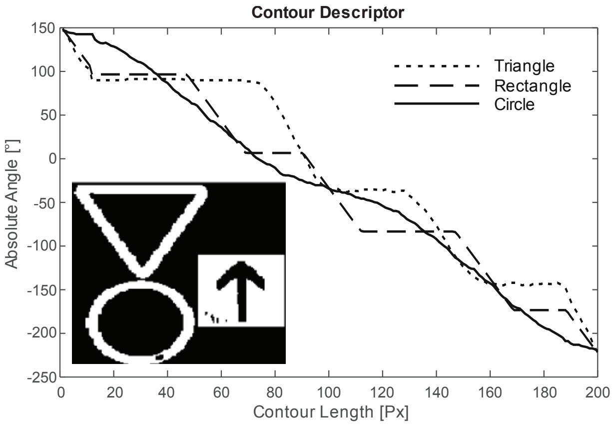


Fig. 3. Contour descriptor for three types of a shape in one graph.

These figures show direct, normalized contour descriptors, comparison of distorted shapes compared with not distorted ones. Not distorted contour descriptors are reference descriptors that are shown in Fig. 1a to 1c.

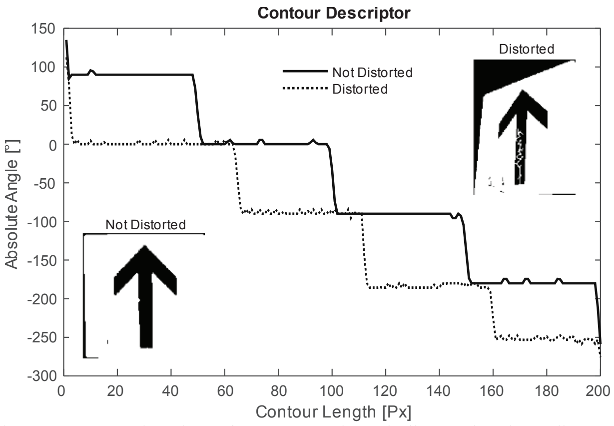


Fig. 4a. Contour descriptor for a square shaped, distorted and not distorted traffic sign (traffic direction).

Distortion of rectangle shaped signs influence on the contour descriptor in the manner of making corner transitions sharper, but with the same number of stairs. Stairs lengths are somewhat different than reference one, but that is a result of distortion where the shape now has edges of different length. Here, the resulting contour descriptor properties clearly indicate and resemble rectangle shaped signs. The calculation time is t=2.55s for both descriptors. With triangle shaped signs, distortion has less influence than with rectangle signs. In Fig. 4b can be seen that all elements of the triangle contour descriptor are here (number of stairs) but differ in the angle change (a corner of the sign) of the contour descriptor. That difference is the result of a coarser image and sharper corner transition. A straight portion of shapes differs in length, but not significantly, and are result of the distortion. In this case, the contour descriptor clearly resembles the triangle shaped signs. The calculation time is t=7.3s for both descriptors. The circular shaped signs are the most tolerant to spatial distortion. As shown in Fig. 4c, the contour descriptors of the reference shape and the analyzed one are very similar which clearly indicates that the analyzed shape is circular.

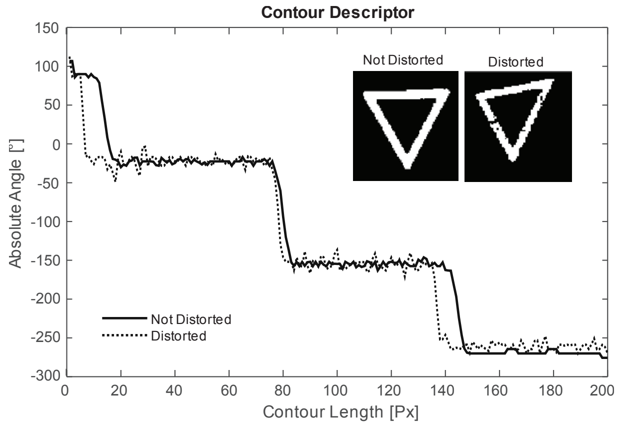


Fig. 4b. Contour descriptor for a triangle shaped, distorted and not distorted traffic sign (Warning – lower priority road crosses higher priority one).

This kind of traffic signs has excellent distortion invariance when the contour description method is used. The calculation time is *t=4.48s* for both descriptors.

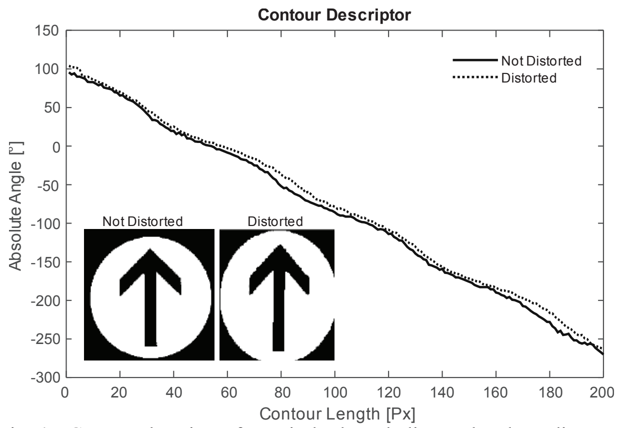


Fig. 4c. Contour descriptor for a circle shaped, distorted and not distorted traffic sign (mandatory traffic direction).

One of unusually shaped signs that have no shape-related category (circle-prohibitory, triangle-warning, and rectangle-information) is an octagonal STOP sign. Its shape indicates and gives, without misinterpretation, a unique command, mandatory STOP. Many of the methods often wrongly detect this sign as circular one even in the close vicinity of the sign. That is especially augmented when an acquired image has poor resolution or sign is far too small in the analyzed scene. Fig. 4d shows the results of the analysis with the contour tracing method applied to the coarse STOP sign image and the distorted one. The coarse image is a result of the image segmentation of the STOP sign that is far away in the scene. From the contour descriptors can be noticed that both descriptors have some similarities, especially when the number of straight portions that indicates a number of sign edges, are counted. It could be seen that the STOP sign has eight straight portions of the contour descriptor that resembles octagonal shape.

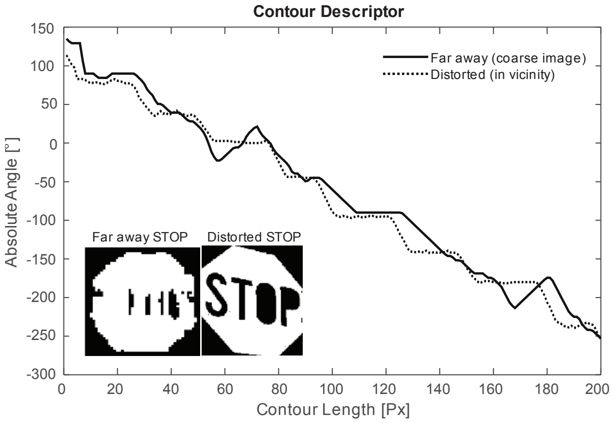


Fig. 4d. Contour descriptor for an octagonal shaped, distorted and not distorted traffic sign (mandatory STOP).

The descriptor of a distorted sign shape has clearly defined stairs and stair slopes and without mistake it could be identified with the octagonal shape even as a distorted one. Finally, both descriptors clearly distinct octagonal shaped signs from the circular one. Of course, deviances in the form of glitches in the contour descriptor are directly related to the coarseness of the image and they improve when the resolution of the analyzed image rises. Based on figures 4a to 4d, the contour descriptor for the distorted shapes does not differ much from not distorted one. Therefore, contour descriptors direct comparison does not require any special further analysis. It can be directly compared to the contour descriptor from the database.

V. Conclusion

The automated traffic sign recognition has an important role in assisted and autonomous driving processes. Primarily to diminish human error by eliminating traffic signs misperception or misinterpretation and secondly, to enable and set a ground stone for fully autonomous transportation systems development in the near future (and today). The whole process consists of several sub-operations causally related (chained). Starting from traffic sign detection, where for that purpose a union filtering of image color properties in HSV color space is used. Then by applying the contour descriptor method onto segmented image areas containing a sign which results in a specific contour description. Descriptor describes each shape and uniquely identifies a shape of a traffic sign (triangle, square, circle or octagon). The last operation is related to the contour descriptor comparisons and evaluates their differences. After all, the proper shape identification enables to select a specific group of signs for the sign content identification. Therefore, reduces the time for searching the sign in a database for roughly three-times (based on the assumption that there is an equal amount of circle, triangle and rectangle shapes used for traffic regulation).

Another aspect of this method appears, especially in the area of the distorted shape analysis. For distorted traffic signs, the analysis results show that the contour descriptors of the reference and analyzed shape do not differ much. They are highly similar and have all elements that describe a specific shape. Such elements are the number of stairs in the descriptor (indicates the number of straight portions in a sign shape), slope of stairs (indicates the presence of round corners or structures in a sign shape), sloped lines (indicates the presence of circled structures, primarily on circled signs) and sudden changes in descriptors (indicate sharp, often related to corners, transitions). For the traffic sign shape recognition, the main differences are visible mostly in lengths of straight contour portions and corner transition sharpness. That is directly related to the spatial strength of sign distortion. After the contour description method is applied and the descriptor is given, there is no need for additional complex analysis steps, just a simple descriptor comparison will do the job nicely.

The method has the ability to recognize a traffic sign shape even on a coarse signs image which is often the result of a sign image segmentation that is far away in the analyzed scene. Application of the method in MATLAB executive environment gives the calculation times between one and ten seconds. These processing times are far from being usable in real-time applications. But, by the translation of the scripted algorithm to higher programming language with programming optimizations related to computer architectures, additional calculation boosts are expected and will be one of the focuses in future research work.

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