DriastSystem: A Computer Vision Based Device for Real Time Traffic Sign Detection and Recognition

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Abstract. This paper presents the design and application of novel device for real time traffic sign detection and recognition on a hardware platform powered by Intel® Atom^{TM} processor. Image frames from standard and relatively cheap web cameras are processed using OpenCV library [7][2]. An innovative method is proposed for traffic sign detection phase. Two color models are used for image segmentation and detection of traffic sign. Many well-known and described tactics have been tested and rated. Implemented in OpenCV Library functions for pattern recognition method are also used in main algorithm. Experimental results of traffic sign detection and recognition are described. The prototype was implemented as part of the Master Thesis at Cracow University of Technology [1].

Keywords: computer vision, traffic sign detection and recognition, OpenCV library, color model, pattern recognition, fuzzy logic.

1 Introduction and Motivation

The problem of traffic sign recognition is quite popular in the field of computer vision technology, but it is very often processed with previously collected data. In many cases these data are represented by several short videos recorded in similar weather conditions. Nowadays, this type of approach is useless because system is adapted to the specific type of circumstances and it will be ineffective for new data.

There were many attempts to solve this problem undertaken by teams of scientists and corporations dealing with modern technologies, as well as car companies. On the other hand, commercial proposals are not documented in terms of their construction and actual quality of the recognition effectiveness. What's more, they are inaccessible to regular user because of their price and intellectual property protection.

Due to the miniaturization of high speed computing systems and the systematic decrease in their prices, it is possible to build mobile device that would tackle

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the problem in real time on the vehicle's board. Designed prototype meets this requirement. For proper operate performance it requires only a standard 12V power supply available in each vehicle. The device is relatively inexpensive, as well as fully mobile. It can also be regularly updated without affecting software installed in on-board computer.

Fig. 1. Different templates of traffic signs in some countries

Individual templates of traffic signs depend on the country where they are approved. It was additional motivation to build a device adapted to Polish conditions. In each country traffic signs differ not only in shape and color but also the pictograms placed on them are different. The found solutions are designed in U.S.A. and Japan, so probably they would not be effective in Poland. As may be seen in figure 1 traffic signs differ in shape and color.

Related Works. At present - the end of 2011, in addition to the above mentioned Ford Focus, traffic signs recognition systems are available in several car models, which are among the most expensive. Such improvements can be found among others in the Audi A8, Saab 9-5 and the productions of the Mercedes-Benz S Class. However, these are high-end vehicles, also equipped with other intelligent systems, and traffic sign recognition module is only one of many subsystems. None of these solutions has officially available documentation clearly defining their structure and effectiveness.

Siemens's project was implemented in 2008. Its primary purpose was to reduce the number of breaking the speed limits on highways, therefore it was limited to the recognition of speed limit signs. It is integrated with on-board computer and in some car models, it can automatically influence the speed of the vehicle [3]. Wider approach to the problem has been suggested at the IEEE Computer Society International Conference on Computer Vision and Pattern Recognition by Michael Shneier. His project included a methodology that allows to recognize the signs of all subgroups [4]. The prototype version of the camera device that downloads images from the road environment was placed on the roof of the car. The quality of detection and recognition was determined on the basis of several pre-prepared videos and amounted to about 88% and 78%. Also an interesting solution for the circular traffic signs recognition has been proposed by a team of researchers from Nagaoka University of Technology in Japan and the Institut

Teknologi Nasional Malang in Indonesia [5]. At the beginning, fragments from the collected samples were isolated. To isolate them, researchers used the geometric fragmentation, which is similar in its assumptions to Genetic Algorithms.

2 System Design

The components of the system can be divided into two main groups. The first is the hardware part, which brings all the components together. All of them can perform required operations in a relatively simple way for implementation. The second group combines the application modules, and running processes which performs various tasks. Graphical application interface was developed in an environment with Qt signals and slots mechanism[6]. Additionally, to notify driver about passing traffic sign, voice messages are played and information is presented on the monitor. Instead of using embedded operating system, Ubuntu Server edition is used.

2.1 Hardware

During the selection of hardware platform many solutions including the AVR and ARM microprocessors have been tested but their performance is low for this type of system. Finally, the platform with built in Intel Atom Processor has been chosen. Atom series processors are a relatively new solution proposed by Intel Corporation to build small, energy-efficient computing system fully compatible with 32 and 64 bit architecture. Small size motherboard, low power consumption of the entire set (50W) and low emission of heat in conjunction with the performance of the standard unit makes this solution ideal for this project implementation.

Asus motherboard AT3GC-I has been chosen as a stable foundation for the Intel Atom CPU and 2GB DDR2 800Mhz RAM. Instead of the standard 2.5" or 3.5" hard drive, system uses a Ultra CompactFlash card with a capacity of 8GB and write speed of 30MB/s. All components have been installed in a compact computer case in MiniITX format and powered with a universal power supply used in portable computers.

2.2 Main Algorithm

The central element of the system and the entire device is the algorithm responsible for traffic signs identification. Each video frame taken from camera mounted in the vehicle is subjected to preliminary processing in order to prepare it for the next steps of the main algorithm. The effect called 'digital image noise' causes the appearance of erroneous final results. To overcome it, a series of transformations has been applied to the image. Also an appropriate sequence of actions and transformations has been developed in order to increase the effectiveness of the algorithm. Image smoothing was performed and the technique of image pyramids has been used. Source image has been converted to HSV color space, and each channel of RGB and HSV models has been isolated into separate arrays.

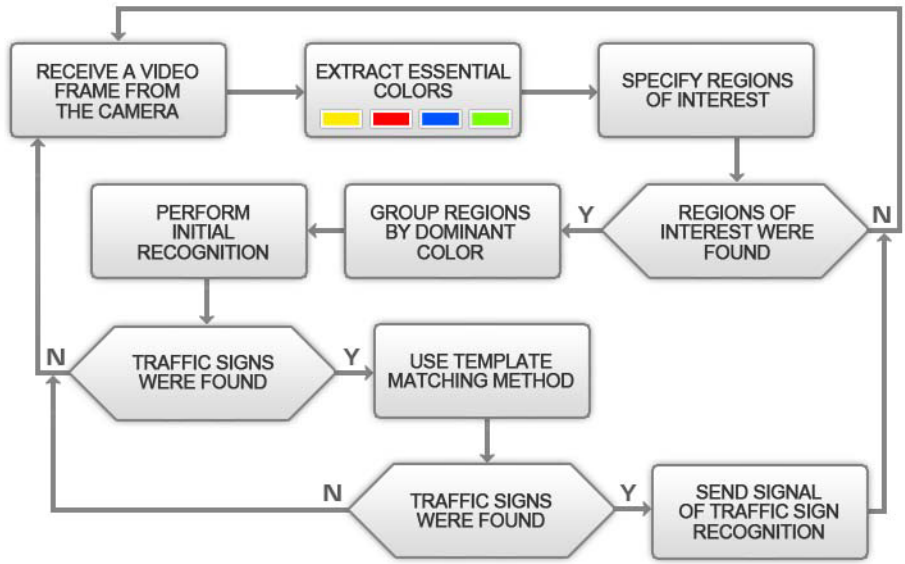

Fig. 2. System workflow diagram

Detection Phase. Following the initial stage of processing and standardization of the camera image is a phase of traffic signs detection. It involves the segmentation of a single image to isolate smaller areas, which may contain essential objects. The rejection of as many fragments of the original image as it is possible significantly affects the efficiency of subsequent steps. It directly involves a number of calculations that must be made in the recognition phase.

The main idea used at this stage of processing is to identify parts of the image, which have specific characteristics - for example, hue and saturation in the HSV model. So-called 'color maps' are created and used in logical sentences as arguments. They determine the logical group of pixels of given properties. With the characteristic structure of the HSV color space it is possible to determine the approximate location of three existing traffic sign colors - yellow, red and blue in this color space. Hue frequency distributions for each group of signs were determined by additional program, which was designed for this task. This was done by analyzing the components of hue (H) and saturation (S) of the HSV model in individual pixels located on the prepared samples of signs. 200 samples were prepared for warning signs, 100 for regulatory and 100 for prohibition signs. Distributions were then normalized to the interval $< 0; 1 >$.

In the standard approach to the problem, detected areas are compared with the distribution of the averaged just by using the membership function. Subjects of fuzzy logic, such as fuzzy set are used here. Then the probability when a given area may be an interesting object is determined.

This approach is often used and generally gives satisfactory results. The schema using the HSV model is characterized by the extracting image segments closest to the previously set color. This algorithm focuses on the most narrow region of interest through the systematic rejection of all fragments, which do not meet the assumptions and keeping those that comply with them. However, under studied conditions, it turned out to be unreliable.

In order to solve the problem an innovative method has been developed. It combines the approaches from the RGB and HSV models. In addition, it aggregates both models. The aim is to make the best detection of traffic signs reject as many unwanted regions of the image as it is possible. Proposal for innovation of the developed method can also be supported by Karla Brkic's studies from University of Zagreb, who compared 11 papers describing the approach to the problem of recognizing traffic signs. Each of them was connected with one of the color space model. There is no solution which uses simultaneously two models [9].

Fig. 3. Improving the extraction process by using the proposed method

Intervals containing acceptable hue and saturation values for each color have been extended to prevent rejection of too many important areas. The new values are presented in table 1. What's more, the analysis of each pixel is derived by its properties in two color space models - RGB and HSV. In most cases it is much easier to discover dependencies involving image segmentation based on two or more models. For each pixel hue and saturation value from HSV model and red, green and blue value from RGB model are checked simultaneously. Only if all of these assumptions are satisfied the pixel is considered to be significant and it is placed in the set of pixels of a given color e.g. for yellow pixel the following conditions must be met in HSV color space model:

$$H_{val} \in (10;85) \wedge \; S_{val} \in (45;255);. \tag{1}$$

and RGB color space model:

$$R_{val} \in (125;220) \wedge \; G_{val} \in (90;145) \wedge \; B_{val} \in (0;45)\;. \tag{2}$$

Green and red pixels are classified in the same way but with different ranges. It has been observed that for blue pixels this procedure is not necessary and standard approach also gives satisfactory results.

In the project it has also been proposed to use CMYK for the extraction of the regions with white and black color. The CMYK color space model is rather used in polygraphy - not in issues related to the computer vision, but preliminary tests showed that using this model could be beneficial in this case. It should be noted that this model has also a separate channel 'Y' for yellow color, as it is important in the case of Polish traffic signs.

Table 1. The modified components of hue and saturation for the four colors

COMPONENT	RED	YELLOW	BLUE	GREEN
(H) Hue	(0; 35)	(10; 85)	(90; 155)	(10; 110)
(S) Saturation	(50; 255)	(45; 255)	(40; 205)	(0; 180)

Expanding ranges of hue and saturation parameters showed in table 1 imply a further innovation in this approach. The color already extracted are used for the following extraction of the areas in specified color. In addition, exploration field is not drastically but gradually narrowed in each step. For example, in order to detect the warning signs, first determined regions are colored yellow, orange and red. Then, extraction of yellow color is carried out, which is easier when the search area was initially narrowed. This is done with adaptive thresholding, which in this case highlights its advantages over standard thresholding. The described approach can be traced in the figure 4.

Fig. 4. Gradual extraction of yellow areas

Extraction of colors that do not appear on traffic signs brings positive results. An example would be a green color which is not seen on the relevant traffic signs and its extraction helps to indicate the yellow colored areas by the application of a logical difference operator. Green mask is subtracted from the mask containing yellow color. This makes sense due to the fact that these two colors are near each other in both color space models - RGB and HSV.

Recognition Phase. At the moment the device has a lower efficiency in this phase as compared to competitive solutions. More sophisticated methods like neural networks or SVM have not been applied yet. Features defining tests have been carried out so that they would be sent to SVM, but none of them has given satisfactory results. All areas that have been classified at the previous stage, as segments, which may include a traffic sign are sent to the recognition phase. They are initially grouped according to the dominant color - yellow warning signs, red - prohibition signs and blue - mandatory and information signs.

On most road signs there are pictograms that define their meaning. To prevent a situation where the sign's template would be incomplete, new method has been developed called 'Expanding the Region of Interest Method'. Area sent from the detection phase is enlarged for so long that within it there are important pixels described by a given color mask. Note, that there have been many transformations with image segment which is processed, including blurring and smoothing, so it is suggested to do the kind of one step back. Portion of the image is taken from the untransformed sample source for analysis. This is advantageous because the operations useful at detection stage are not necessarily useful at the moment of recognition.

Pattern Matching Method has been used to recognize the traffic signs. To maximize the chance of correct identification of all not rejected segments, all areas are scaled to the same size 100x100 pixels. The next step involves using the cvMatchTemplate function, which is available in OpenCV library. It returns the maximum and minimum fit of the pattern to the part of the image. These values are normalized to the range $< -1; 1 >$. The decision to recognize a traffic sign is based on the best fit value. In algorithm the correlation coefficient method has been used, where correlation coefficient is between -1.0 and 1.0. Extreme values represent the worst and the best fit. Value 0.0 represents no correlation. This method matches a template T relative to its mean against the image I relative to its mean and the result R is given by the following formula[2]:

$$R_{ccoeff}(x,y) = \sum_{x',y'} [T'(x',y') * I'(x+x', y+y')]^2 \; . \qquad (3)$$

where:

$$T'(x',y') = T(x',y') - \frac{1}{(w*h) \sum_{x'',y''} T(x'',y'')} \; . \qquad (4)$$

$$I'(x+x',y+y') = I(x+x',y+y') - \frac{1}{(w*h) \sum_{x'',y''} I(x+x'',y+y'')} \; . \qquad (5)$$

To save resources, pattern matching is done in stages. For each color group of signs, first attempt to identify the characteristic signs is taken. In case of prohibition signs, STOP sign is recognized at the beginning. If the established conditions are met, the search is terminated at this stage. Otherwise, an attempt is made to recognize B-35 or B-36 sign. Finally, all other prohibition signs are searched.

Table 2. DriastSystem and other solutions comparison

SYSTEM	(1)	(2) [%]	(3) [%]	(4) [%]	(5)
Siemens VDO	n/a	n/a	n/a	n/a	YES
Road Sign Det. and Rec.	92	88.0	78.0	6.5 - 58.0	NO
Intell. Machine Vision	n/a	n/a	95.5	n/a	NO
Driast System	714	88.2 (94.8)	71.2 (91.0)	22.1 (4.2)	YES

(1) - Number of signs on samples, (2) - Detection quality, (3) - Recognition quality

(4) - Percent of faulty recognitions, (5) - Real time tests

3 Experiments

Tests for each traffic sign appearing in a set of recognized signs has been carried out using collected samples. In each case 20 representative images with a sign, and 80 random samples with other sign or only background have been selected. Most important signs, indicating the priority on the road were also separated. In this case the number of test samples has increased twice. This group included D-1, D-2, A-7 and B-20 signs. In case of these signs tests have been made in real time during regular travel by car. Due to the very limited time, official tests for other signs were limited to samples in the form of images. Comparison of the average efficiency of the prototype built with the described solutions is presented in the table 2.

During tests there were also numerous false indications, number of which should be reduced. The applied patterns are fragments of the original signs templates. Using averaged image pattern, modeled on the slices of test samples, better results could be obtained. But this would require some time to prepare templates. It is noteworthy that beside the simplicity of the pattern preparation process, this method has already given satisfactory results at this stage and could be further developed or supported by other mechanisms. Currently, mechanisms enabling recognition of more than 30 traffic signs of various types have been implemented in the main algorithm.

4 Summary

So far, a solid foundation for the development of our device has been built. Already at this stage fairly good results has been achieved, especially for the detection phase. However, they require further improvements for the recognition phase. Developed tool clearly shows the capabilities of vision systems, and digital image processing algorithms. A few dependencies that can be used in a similar type projects have been noticed.

The greatest innovation which is characterized by the algorithm is a completely different approach to the given problem than the one which have already been described by the developers of such tools. Simultaneous use of two color space models has given much better results than relying on only one of them. Another advantage was achieved by the introduction of methods for expanding the region of interest and by dividing almost all steps into smaller threads. The progressive narrowing of the problem field is a more effective approach than trying to achieve high results at the very beginning.

While working at main algorithm several methods for this purpose have been tested e.g. Cyganek's method of essential points[8]. However, they have not given satisfactory results for recognition in real time.

Development Possibilities. Like any prototype device it requires a further contribution of the work. It could be improved and developed at the hardware and software level. To make it more attractive to potential users, it should be miniaturized. A software layer also requires permanent improvements in performance and quality.

Using the experience gained so far in the field of computer vision and structure of OpenCV library, it would be possible to introduce additional functionality, such as the detection of horizontal signs and traffic lights. Set of recognized signs also should be expanded, but it involves additional tests and re-execution phase of data collection.

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