

# Traffic Sign Recognition System based on Cambridge Correlator Image Comparator

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**Abstract**— Paper presents basic information about application of Optical Correlator (OC), specifically Cambridge Correlator, in system to recognize of traffic sign. Traffic Sign Recognition System consists of three main blocks, Preprocessing, Optical Correlator and Traffic Sign Identification. The Region of Interest (ROI) is defined and chosen in preprocessing block and then goes to Optical Correlator, where is compared with database of Traffic Sign. Output of Optical Correlation is correlation plane, which consist of highly localized intensities, know as correlation peaks. The intensity of spots provides a measure of similarity and position of spots, how images (traffic signs) are relatively aligned in the input scene. Several experiments have been done with proposed system and results and conclusion are discussed.

## I. INTRODUCTION

Video – based object recognition has many applications in different fields. There are many types of recognition systems because each of application has its own specific requirements for input data [7]. It's too hard or maybe impossible design system for all applications, because each application need input data with specific parameters and in specific form [10,15].

Driver Assistance System (DAS) consists of many types of systems which help to driver keep driver and crew save [10,14]. Nowadays are DAS very popular and many car designers use this system in new cars in the form of Park Assistance Systems, Traffic Sign Recognition System, etc. [5,6,9]

In this paper we will focus to Traffic Signs Recognition System. Video processing considers very high speed of processing. Most of designed Traffic Sign Recognition Systems are based on Shape detection and Color segmentation [13], Automatic Detection and Classification of Traffic Signs, Real Time Road Signs Recognition [8].

This paper is concentrated to Traffic Sign Recognition System as a one part of DAS. Our system is based on Optical Correlator, particularly Cambridge Correlator is used [3,6]. Optical Correlator is device which can compare two images in very high speed. This fast comparing can be very helpful in recognition part of the proposed system. Using Cambridge Correlator, we can reduce process time of traffic signs recognition. Cambridge correlator belongs to family of Joint Transform Correlators (JTC). Correlator use Optical Fourier Transform (OFT) to produce Joint Power Spectrum and then Optical Cross – Correlation between

input images. Cross – correlation is produced in real time, so all restrictions are in preprocessing of input data and identification of traffic sign [1,3,4].

The paper is organized as follows. Chapter II explains some important details of Optical Fourier Transform implementation. Chapter III is devoted to detail description of Cambridge Correlator (main parts and principle are described). In Chapter IV Traffic Sign Recognition System is described. This chapter is devoted to Hardware Scheme of proposed system. Experiments and Results are in Chapter V. Experiments were done with static images captured in real traffic scenes in Slovakia. Results of recognition are recorded in tables. Conclusions are covered in Chapter VI.

## II. OPTICAL FOURIER TRANSFORM

### A. 2D Fourier Transform

The Fourier transform (also called Fourier spectrum or frequency spectrum) of function (in general complex-valued)  $g$  of two independent variables  $x$  and  $y$  will be represented here by  $F\{g\}$  and is defined by [1,2]

$$F\{g\} = \int \int_{-\infty}^{\infty} g(x, y) \exp[-j2\pi(f_x x + f_y y)] dx dy. \quad (1)$$

On Figure 1 is showed 2D function  $g(x,y)$  (square) and its Fourier Transform,  $F(g)$ . These examples were produced using MATLAB simulation software.

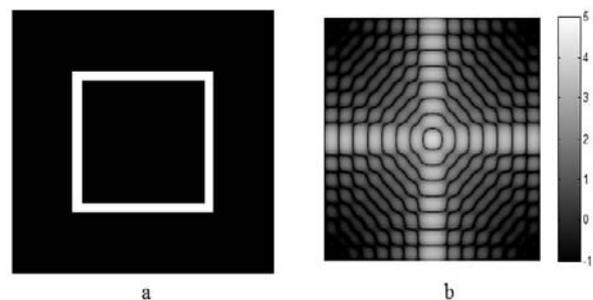


Figure 1. Square and its Fourier Transform.

The Fourier transform so defined is itself a complex-valued function of two independent variables  $f_x$  and  $f_y$ , which we generally refer to as frequencies. Mathematical operations for the Fourier transform and inverse Fourier transform are very similar, differing just in the sign of the exponent appearing in the integrand in formula (1).

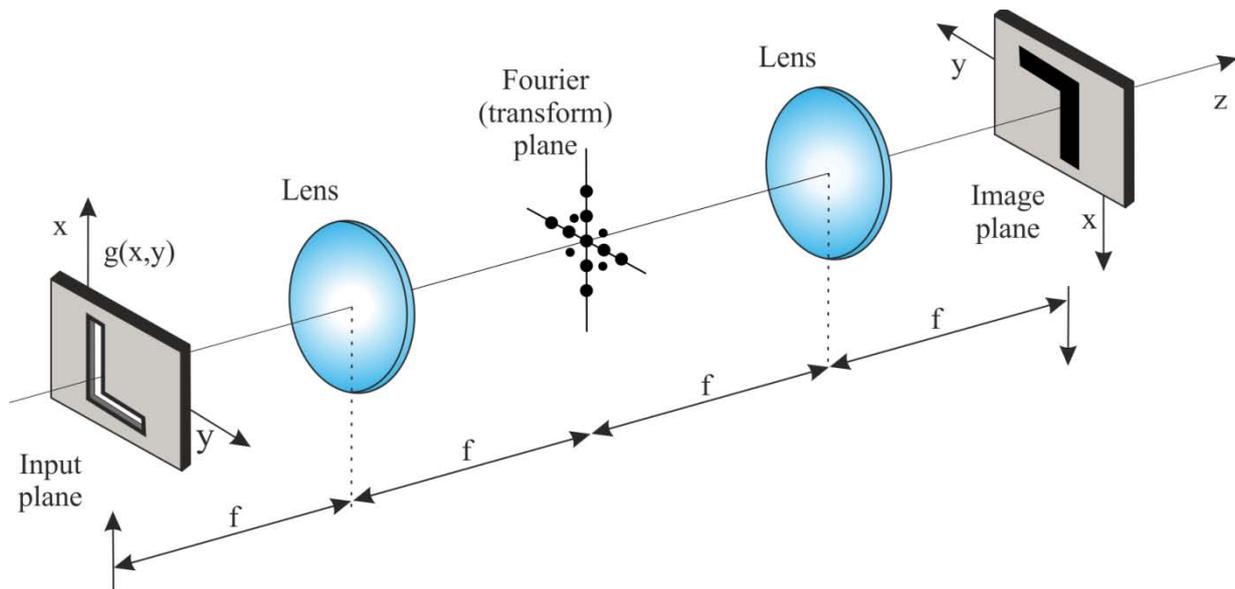


Figure 2. Optical Fourier Transform.

**B. Optical Fourier Transform Implementation**

Fourier Transform of 2D data or image as is defined above can be realized by mathematical operations or using optical lens [1,2,12]. Optical lens makes in focus of the lens the Fourier Transform of image.

In Figure 2 is shown 4-f optical system (distance between input plane and image plane is 4 times focus of one lens, 4\*f). In this Figure 2 we can see that, in focus of first lens Fourier Transform occurs. Using another optical lens we get inverse Fourier Transform and finely we get original image (as it is shown on Figure 2).

Using masking filter in Transform Plane of 4-f system we can make masking filter (frequency filtering), which can remove some lines, shapes or contours from original image and so obtain new modified images [12]. Principle of masking of Fourier Transform in 4-f system is used in one type of Optical Correlators, the Match Filter Correlators [1]. In these types of Optical Correlators is reference image Fourier transformed “off line”, using mathematical operations, and Fourier Transformed reference image is used as masking filter in 4-f system. Output of this system is correlation peak if match was detected.

Optical processing (Fourier transform and filtering) is a truly parallel method of calculation, using the fastest medium – the light. Because of the process is parallel in nature, the process time does not scale with image resolution. This allows very large images to be Fourier transformed at the speed of the light [3,4,6].

All advantages of Optical Fourier Transform, mostly real time processing with images, are implemented in Optical processors to compare two or more images, for example, Optical Correlators. There are two main types of Optical Correlator, the Matched Filter (MF) and Joint Transform Correlator (JTC). Both types achieve largely the same results, but process the information in different ways [1,3,6].

**III. OPTICAL CORRELATOR**

Optical Correlator is device to compare two images in very high speed. Image data that enter to the optical

system is compared during correlation process in terms of two criteria, similarity and relative position. Comparing is done between reference and input image. Reference image could be some image from database and input is image captured by external camera.

There are two types of correlator, Matched Filter and Joint transform Correlator.

**A. Matched Filter**

This type of correlator is based on Vanderlugt Filter, invented by A. Vanderlugt in 1964. It is very sensitive to build, owing to its strict alignment criteria and long optical train, but still is commonly used type of Optical Correlators. The process involves obtaining two Fourier Transforms, of “input” and “reference” and the results of these transforms is optically multiplied and Fourier Transformed again as it shown in Figure 3. Usually, the reference image is transformed off-line, using electronics (FFT) to obtaining filter, Match Filter. This Matched Filter is than shown on Spatial Light Modulator, (SLM) as a masking filter mentioned above. These two Fourier Transforms are optically multiplied to obtain Optical Correlation. The most advantages of this method are high space – bandwidth product and extremely fast process time, but disadvantage is the need to create reference filter, Matched filter from reference image, so also need reference image before correlation process [3,4].

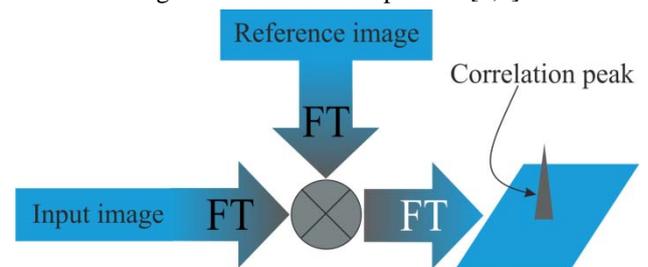


Figure 3. Matched Filter Correlator.

**B. Joint Transform Correlator**

The Joint Transform Correlator (JTC) was invented by Weaver and Goodman in 1966 and is traditionally the less

commonly used of the two designs. The process differs significantly from the Matched Filter process, since no reference filter is required.

JTC use “Input” and “Reference” images aligned and displayed alongside each other on SLM as is shown in Figure 4 [3]. These before single images are now Fourier Transformed together. A non – linearity (mostly a camera or photodiode array) then captures the intensity distribution of transform to produce Joint Power Spectrum, (JPS) [4].

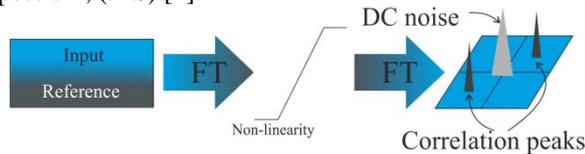


Figure 4. Joint Transform Correlator.

JPS is then binary or threshold processed and this processed image enters to transform process as input image of second Fourier Transform. Output of this transform is correlation plane include correlations peaks per match. This found match is shown as highly localized intensities and the intensity of peaks provides a measure of similarity of the images being compared whilst position of spots denote how the images are relative aligned in the input scene.[3]

The most advantages of this method of correlation are the simplified optical train (and therefore much cheaper to produce) and no strict alignment criteria.

To this family of correlators belongs also Cambridge Correlator [3,4], which is used in our system to recognize traffic signs.

C. Cambridge Correlator

Cambridge Correlator (CC) [3,4] is developed by Cambridge Correlators Ltd. and it belongs to group Joint Transform Correlators.

1) Optical system

Optical system of CC is based on Fourier Transform Engine© - a compact, yet hugely powerful processing system, built on the diffraction principles of the Optical Fourier Transform. Its new “W” design allows the electro – optical components to operate at their full potential.

In Figure 5 are shown main parts of CC [3].

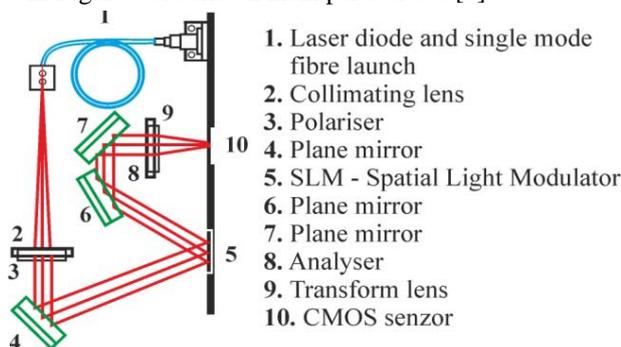


Figure 5. Basic components of Cambridge Correlator.

The Spatial Light modulator is driven from the DVI port of the PC via its own drive board. In TABLE I. are shown main parameters of used SLM.

TABLE I. SLM PARAMETERS [4]

Resolution	1280 x 720 pixels
Bit Depth	8 – bit grayscale
Input frame addressing	60 Hz (DVI port addressing)
Pixel size	9,5 micron pitch, 0,55” diagonal active area
Liquid crystal	Vertically Aligned Nematic cell
Response Time	10 ms ± 5 ms
SLM frame refresh	120 Hz

Images displayed on the SLM are illuminated with a collimated low power laser beam, launched through an optical fiber. The light is modulated by the images displayed on the SLM and then projected through the lens system.

The camera used in the kit is Leutron PicSight camera, with Gigabit Ethernet interface. Frame rate of camera is up to 200 Hz and the resolution is VGA resolution, 640 x 480 pixels [4].

2) Fourier Optics Experimenter

Cambridge Correlator described above is coupled with simulation software, “Fourier Optics Experimenter (FOE)” to learning and easy understanding Fourier Optics, especially Optical Correlation. FOE allows make Optical Correlation based on Cambridge Correlator between two or more images (videos), (Figure 6).

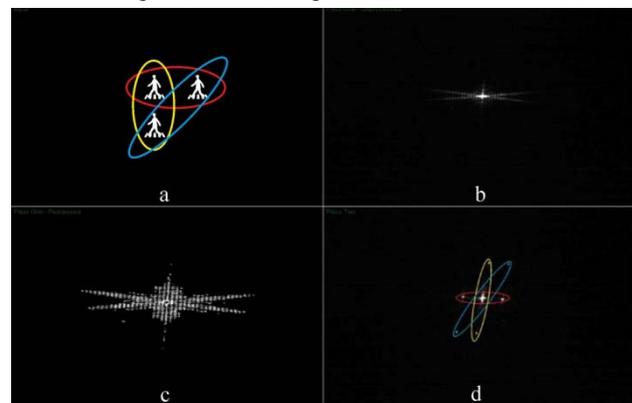


Figure 6. Correlation between three same symbols.

In Figure 6 we can see correlation between symbols of “CROSSWALK”. In Figure 6a is input plane shown where three symbols were added. In Figure 6b of image we can see Joint Power Spectrum (JPS) of whole image (three symbols). This JPS is binary or threshold processed (Figure 6c.) and transformed again. Output of this correlation is showed in Figure 6d.

Correlation consist of three pairs of correlations peaks, because three matches were detected. These peaks are coupled on Figure 6d as match was detected (peaks in red circle in Figure 6d is match between symbols in red circle in Figure 6a). This advantage of Joint Transform Correlator can make more than one optical correlation in one time. So we can compare more images in one correlation process and to save process time of recognizing any patterns.

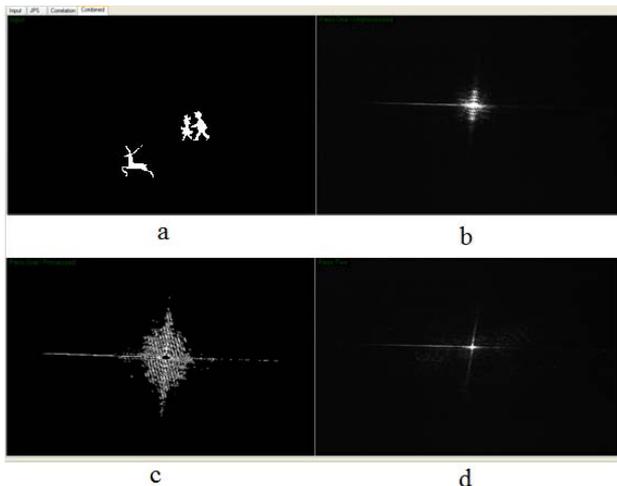


Figure 7. Correlation between different symbols.

For two different images no correlations peaks are showed in correlation plane. In Figure 7 we compared symbol of “children” with symbol of “animals”. Joint Power Spectrum looks very similar but in Correlation plane no correlations peaks were detected. Correlation plane consist of just DC noise (Figure 7d).

#### IV. TRAFFIC SIGN RECOGNITION SYSTEM USING CAMBRIDGE CORRELATOR

Traffic Sign Recognition System is one of most important part of DAS mentioned in Introduction. Nowadays are these systems very popular. Many designers of cars use these systems in new cars to produce more comfortable and more security for drive and crew.

The Traffic Sign Recognition Systems offer information of the road signs on the way and guide the driver. In DAS, it helps the driver to identify the traffic signs earlier and precisely. In ideal light conditions this system could avoid false recognition (or misleading recognition) of traffic signs caused by various human factors (inattention, tiredness, sleepiness or micro-sleep). Thus, the traffic sign recognition system makes the driving safer and easier.

Traffic sign recognition system is generally an intelligent vision system used for traffic signs recognition in the traffic scene. The traffic sign recognition in outdoor traffic scene, due to illumination changes (day, night, haze, snow, fog, rain, etc.), shadows, partial occlusions, sign rotation and damage becomes a very challenging and difficult task [7,10].

Fast process time is very important aspirations for real - time recognizing. The proposed system to recognize traffic sign use Cambridge Correlator to compare reference and input image in real time, so there is more short processing time.

##### A. Hardware scheme

Hardware scheme of proposed system is shown in Figure 8. System consists of four main parts: 1.Color Camera (CMOS sensor), 2.Computer Unit, 3.Optical Correlator (Cambridge Correlator is used), 4.Display. Traffic Scene is captured by color camera, preprocessed in computer, compared in Optical Correlator and correlation is evaluated in same computer, which was used to preprocessing. Output is shown in Display.

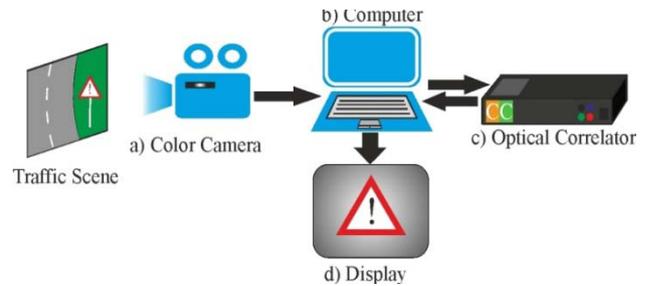


Figure 8. Traffic Sign Recognition System.

#### B. Recognition Proces

##### 1) Capture of Traffic Scene

Traffic scene is captured by the color camera (CMOS). Key frames are extracted from captured video sequence. These frames are preprocessed to minimize of DC noise in correlations process.

##### 2) Preprocessing

Preprocessing consists of detection Region of Interest - ROI (detecting potential Traffic Sign). ROI is obtained by filtering of relevant colors of traffic signs (red, blue, yellow and green). After color filtering, irrelevant color clusters are removed. After this preprocessing just relevant objects are available. These potential ROIs are defined and they are marked as input to optical correlator.

##### 3) Optical Correlation

Detected ROIs are compared in Optical Correlator with database of reference Traffic Signs. In correlation plane the position of correlation peaks define recognized Traffic Sign. Position of correlations peaks is represented by position of Traffic Signs (detected Traffic Sign in traffic scene relative to reference traffic signs). This information may be used in Traffic Sign Inventory Systems.

##### 4) Identification and Display

Output of Optical Correlator, correlation peaks, goes back to computer unit to detecting of position of correlation peaks. Then Computer unit is used to Identification traffic sign in input plane of Optical Correlator.

The developed system was tested on traffic scenes captured on road of Slovakia. Traffic scenes were obtained in daylight conditions.

#### V. EXPERIMENTS AND RESULTS

##### A. Experiments

##### 1) First experiment

In this experiment with traffic sign recognition of four Traffic Signs: CROSSWALK, MAIN ROAD, STOP and YIELD was tested (Figure 9).



Figure 9. Tested Traffic Signs in first experiment.

Traffic Signs showed in Figure 9 were used as reference images in correlations process. As is mentioned above, as input traffic signs (signs to recognizing) were used traffic signs from real traffic scenes from Slovakia.

Examples of some traffic scenes used in these experiments are showed in Figure 10.

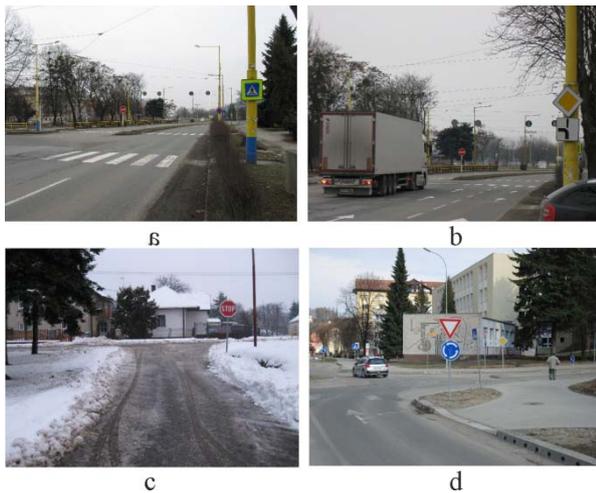


Figure 10. Captured Traffic Scenes.

After background removing of captured traffic scenes just relevant ROI left. These ROIs are normalized for input plane of Cambridge Correlator. Some ROIs examples are shown in Figure 11.



Figure 11. Detected Traffic Signs.

Reference and detected (input) Traffic Signs enter to input plane of correlation process. In this plane the Roberts Cross operators are used to detection of shape of these images. Roberts cross operator minimize DC noise of Joint Power Spectrum and Correlation peaks are simpler detectable. If input plane obtain too much of information, the correlation obtain a big DC noise and correlation peaks are hardly detectable.

Position of reference and recognized traffic signs in input plane can be variable, but position of these traffic signs will represent position of correlation peaks in correlation plane. Identification of traffic signs could be now performed. High intensity peaks are found in before defined area with exactly defined tolerance, so we can determine which traffic sign was recognized.

2) Second experiment

Next experiment with designed Traffic Sign Recognition was done with the same types of Traffic Signs, but they were captured with worse light conditions. Target of next experiment is test designed system in traffic scene with low visibility. In this experiment the same method of traffic sign recognition was used.

Example of traffic scene with low visibility is showed in Figure 12.



a) Traffic Scene with ideal visibility      b) Traffic Scene with low visibility

Figure 12. Example of Traffic Scene with low visibility.

B. Results

Results of experiments with low visibility are summarized in TABLE II. Traffic Signs CROSSWALK are named CW1 – CW6, MAIN ROAD MR1 – MR6, STOP S1 – S6 and YIELD Y1 – Y6.

TABLE II. RESULTS OF TRAFFIC SIGN RECOGNITION

Traffic Sign	Intensity of 1. peak	Intensity of 2. peak	Average Success of Traffic Signs Recognition [%]	
			Ideal visibility	Low visibility
CR1	206	218	81	73
CR2	233	212		
CR3	218	193		
CR4	227	186		
CR5	143	162		
CR6	224	249		
MR1	247	239	70	64
MR2	124	122		
MR3	150	145		
MR4	233	239		
MR5	234	239		
MR6	87	109		
S1	176	201	82	73
S2	192	197		
S3	180	238		
S4	199	208		
S5	244	240		
S6	221	212		
Y1	176	159	68	60
Y2	200	208		
Y3	158	158		
Y4	205	245		
Y5	118	130		
Y6	170	141		

In TABLE II is information about each correlation peak and the intended rate of recognition. From these results we can see that traffic signs MAIN ROAD and YIELD have less success of recognition than CROSSWALK and STOP. This is because the Traffic Signs which have more details obtain more information after Roberts Cross preprocessing. Because of this information, correlation peaks are lighter and detection of these peaks give higher value. This fact helps set threshold level in the system. Also we can see that traffic scenes captured with low visibility has a lower success of recognition than scenes captured with ideal light conditions.

## VI. CONCLUSION

Paper presents the Traffic Signs Recognition system based on Cambridge Correlator. The main information of Optical Fourier Transform and Optical Correlators is also presented.

Traffic Scenes in proposed system were captured by color CMOS camera and key frame was extracted. The key frame was preprocessed and converted to HSV color model. Color filters were designed and used to detected relevant colors of traffic signs. Using these filters ROIs obtain in traffic signs was detected. Correlation between tested traffic signs was determined using intensity value of correlation peaks in JTC correlation plane.

Experimental results demonstrate the main advantage of this system is that using optical correlator, it operates at very high speed compared to other pure software implementations running on PC.

In future we want to focus to preprocessing methods of input information and use preprocessed video as input of Optical Correlator. Another target is using this system for recognition of all types of Traffic Signs. Our focus will be also on implementation of some preprocessing algorithms in hardware using FPGA.

Using this method of preprocessing the process time of whole recognition system would be much reduced. Thanks these improvements could Traffic Signs Recognition System based on principle of Optical Correlator happened very attractive to practical use.

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## BIOGRAPHIES

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