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doi:10.15199/48.2015.12.08

Comparative Survey on Traffic Sign Detection and Recognition: a Review

Abstract. *Developing real-time Advanced Driver Assistance Systems (ADAS) based on video aiming to extract reliable vehicle state information has attracted a lot of attention during the past decades. This ADAS system includes inter-vehicle communication, driver behavioral monitoring, and human-machine interactions. In these systems, robust and reliable traffic sign detection and recognition (TSDR) technique is a critical step for ensuring vehicle safety. This paper provides a comprehensive survey on traffic sign detection and recognition system based on image and video data. Our main focus is to present the current trends and challenges in the field of developing an efficient TSDR system followed by a detail comparative study between different renowned methods used by various researchers. Finally, conclusion followed by some future suggestion is provided to develop an efficient TSDR system is provided. This survey will hopefully lead to develop an effective traffic sign detection and recognition system which will ensure driver safety in future.*

Streszczenie. *System ADAS (Advanced Driver Assistance System) obejmuje także metody rozpoznawania znaków drogowych. W artykule przedstawiono przegląd metod detekcji i rozpoznawania znaków drogowych bazujących na obrazie video. W artykule dokonano oceny istniejących metod oraz zaproponowano środki poprawy ich efektywności.* ***Studium porównawcze metod detekcji i rozpoznawania znaków drogowych***

Keywords: Traffic signs, detection, recognition, Advance Driver Assistance System, current issues and challenges
Słowa kluczowe: rozpoznawanie znaków drogowych, system ADAS

Introduction

Automatic traffic sign detection and recognition (TSDR) is an important research in the field of ADAS. Traffic sign has provide important visual information such as; driving on proper lanes, speed limitation, avoiding obstacles, lanes for pedestrians', direction of destination, roadway access, current traffic condition etc. to help the driver while driving. Failing to notice traffic signs may directly or indirectly lead to some traffic accident. A TSDR system can offer significant information about the traffics and surroundings by detecting and recognizing those traffic signs and give warning to the driver in any special situation while the vehicle is running on the street [1]. An automatic TSDR system can detect and classify traffic signs within images that are taken by cameras or some imaging sensors [2]. The main objective of this system is to ensure drivers safety by understanding this visual language and informing the condition and direction of traffics and alerting the driver in any adverse condition.

Developing a TSDR system is a challenging tusk due to various reasons, such as; motion artifacts, Noisy background and foreground scenery, variable lighting conditions, intensity inconsistencies [3]. In addition, traffic signs may be damaged, partially obscured, faded or blurred, similar man-made objects around the sign can also creates problem regarding the performance of TSDR system [4]. The challenging job of developing a robust TSDR has been intensively studied during the past two decades [5]. It is becoming more feasible as processing power of computer is increasing day by day. Many researchers have been developing different solutions to improve the efficiency of the TSDR system.

The main objective of this paper is to identify some current trends and challenges that are faced by the researchers and followed by some comparative analyses of the different methods and to review the concepts and strategies that have been investigated and finally draw the conclusion and suggestions for further research in the process of TSDR with a view of attaining a robust system.

Sign Database

The traffic sign database is actually a collection of traffic signs with available size and currency and structured in such a way that a computer program can quickly select desired pieces of data. A complete traffic sign database contains all types of traffic signs, which helps the users to become familiar with all traffic signs. Several popular and publically available traffic sign datasets are as follows:

- German TSR Benchmark (GTSRB) [6], [7];
- KUL Belgium Traffic Signs Data set (KUL Data set) [8];
- Swedish Traffic Signs Data set (STS Data set) [1];
- RUG Traffic Sign Image Database (RUG Data set) [9];
- Stereopolis Database [10].

Current Trends and Challenges

The main concept of ADAS system is ensuring driver safety. As traffic sign represents the surrounding of the vehicle so it is an essential part of ADAS. Developing an automatic TSDR system is a tough job as the environment is changing rapidly [11]. Reliability is one of the major concerns in TSDR system [12,13]. As color information is highly unreliable and shape can be changed due to different factors, so researchers tried to use the combination of color and shape information for the development of TSDR system. SVM, Neural Network, Hough Transform are the methods that is used by the researchers to minimize the effect of lighting on TSDR system. Neural Network [14–18] AdaBoost [19,20], SVM method for classification [21–26] Self-organizing maps (SOM) [27], joint transform correlation (JTC) [28] are the key methods used by different researcher to minimize the effect of various lighting. Many new methods like MSER based HOG [29], The Karhunen-Loeve transform [30], Low Rank Matrix Recovery (LRMR) [31], Fuzzy c means (FCM) [32] are the other machine learning algorithms introduced by the researchers. Still, for real time application an effective TSDR system needs to consider all the issues that can affect the system. The issues that needed to be considered while developing a TSDR system is described below:

- *Variable lighting condition*: Variable Lighting Condition is one of the major issues while developing a TSDR system. One of the main two features of traffic sign is its unique color which makes it different from the surrounding environment. This color information is very sensitive to the variable lighting condition. The effect of light changes due to different times of days and weather also [11].
- *Fading and blurring effect*: Illumination of sun and rain is another key issue for TSDR system. Fading and blurring of traffic signs due to illumination of sun and rain can cause false detection which leads to an inefficient TSDR system.

Adaptive thresholding method can be very useful for this purpose. Recently researchers use Hough transformation which is robust in different lighting condition and illumination [19].

- *Affected visibility*: Shadows, the light emerged by the headlights of the incoming vehicles can affect the visibility for a real-time application. Visibility can also be affected by rains, clouds, snow and fog.
- *Multiple appearances of sign*: Multiple traffic sign appearing at a time and similar shape man-made object can cause overlapping of signs and leads to a false detection. The detection process can also be affected by rotation, translation, scaling and partial occlusion. Li et al. in [33], used HSI transform and Fuzzy shape recognizer which is robust and unaffected by these problems and its accuracy rate in different weather condition is; sunny 94.66%, cloudy 92.05%, rainy 90.72%.
- *Motion artifacts*: While running on highways, motion artifacts takes into action and caused blurred images when taken from a running vehicle. Using Low resolution camera can also cause noisy and blurred images. Prisacariu et al. in [34] use Haar-like features and SVM for classification and PWP3D algorithm for tracking to reduce the effect of motion blurr, rotation, scaling problem.
- *Chaotic background and viewing angle problem*: Chaotic background and foreground scenery and continuous changing in viewing angle while running on the street also cause difficulty in the detection process. While using color based approaches, similar color objects in the background of a traffic sign cause overlapping of color. So, these methods cannot detect the expected Region of Interest (ROI) which may conclude to a false detection to the system.
- *Damaged and Partially obscured sign*: Damaged and Partially obscured traffic signs are also creating problem for both detection and recognition if the system includes a shape recognizer. It increases the rate of false detection and reduces the system efficiency. 3D reconstruction method introduced by Soheilian et al [35] can detect the damaged sign from real –time environment.
- *Unavailability of public database*: Lacking of some free and properly organized publically available database has also created obstacles in this research field. There are a very few recognized publically available datasets like GTSRB, KUL, STS are now available.
- *Real-time application*: For real-time application a fast algorithm is needed while the vehicle is operating on highways. A fast algorithm like SVM is needed which has a very low computational time for real time application.

All these factors mentioned above may reduce the performance of TSDR system significantly. For a real-time application, all these factors will come into action. Considering all the issues, a single stand-alone method cannot solve all the problems. Researchers have already developed various methods to minimize the effect of variable lightings, motion blur, damaged sign, fading and blurring problems. Using Eigen-gradients based oriented gradient maps and the Karhunen-Loeve transform [30] is the latest method to minimize the effect of variable lighting. Other than that, Hough transformation, Adaptive thresholding and Adaptive shape analysis, Self-Organizing Map are also minimize the effect of lighting change.

Comparative Analysis

The issues that are stated earlier are the main factors that affecting the development of an effective TSDR system. A combination of different methods can improve the efficiency of the system.

Different combination of machine learning algorithms are used by different researchers and can able to solve different issues regarding the system such as; Probabilistic Neural Network is used by Escalera et al [36] and Sheng et al. [16] which can able to detect and recognize traffic sign in somewhat distorted, noisy or blur background and in variant lighting condition. For applying the TSDR system in real-time environment, a fast algorithm is needed. In [19], a detailed comparison between SVM, MLP, HOG-based classifiers and Decision trees are presented. The experimental results showed that, the accuracy rate of Decision tree is approximately 94.2% which is highest among all, whereas the accuracy of the SVM is 87.8% and that of MLP is 89.2%. In terms of computational time for single classification, the SVM takes 115.87 ms, MLP takes 1.45 ms, and a Decision tree takes 0.15 ms, which is the lowest. For detecting the Speed limit sign, SVM or Decision tree is more suitable than Hough transform and Neural Network. For adding new class, the whole dataset is needed to be changed in Neural Network which takes more computational time than SVM.

In [36], after RGB image segmentation for post processing, Genetic algorithm is used for detection purpose. As Genetic algorithm is not dependent on error surface and can solve multi dimensional and multi directional problem, so the overall detection rate is high. In [16], self-adaptive image segmentation is introduced followed by a geometrical shape analysis to detect and extract the expected ROI. After extracting the expected ROI, Sheng applied the Probabilistic NN to recognize the sign. Hechri et al. [37] is used YCbCr color space transformation and image normalization for reducing the effect of variable lighting, blurring and fading. Neural network improves the accuracy of the system by applying bootstrap algorithm to the system.

Support Vector Machine (SVM) is another popular method for developing a TSDR system. Gil-Jimenez et al. [38] and Prisacariu et al. [39] both use SVM for recognizing speed limit signs. Gil-Jimenez et al. [38] is used SVM with a Gaussian Kernel to detect and recognize the speed limit signs, where 134 blob images are extracted from an image database with a 90% of success rate. Prisacariu et al. [39] is used Haar-like features for detection and SVM for classification which is especially effective in detecting speed limit signs in highways. This method is invariant in motion blur and partial occlusion also. The system includes a hardware implementation which runs at 20fps on 640x480 images. An example is shown in Fig 1.

(a)

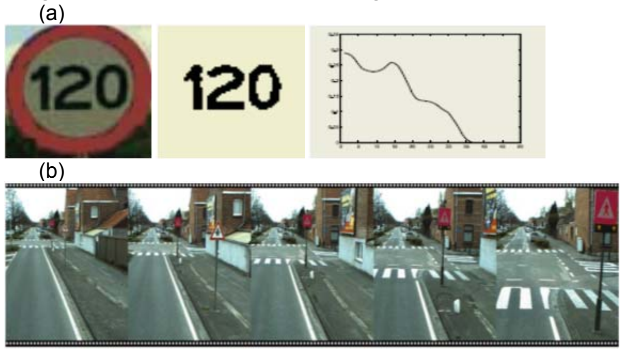

Fig.1. Example of Speed Limit Sign detection using SVM (a) [38] (b) [39]

Hough based SVM is used by Xie et al. in [40] which is invariant in various lighting, rotation, translation, scaling, viewing angle and partial occlusion. Gamma compression and image normalization are used in the pre processing stage for robustness and illumination. For reducing the viewing angle and partial occlusion problem, tri-linear interpolation of the pixel's weight into spatial orientation histogram is used in HoG algorithm and the accuracy rate is

97.72%-99.16%. Liu et al. in [40] is used SIFT matching based SVM for detecting and recognizing broken signs. In this method, images captured from a on board camera and then readjusted by SIFT matching technique to a standard camera axis and compared to a reference image by SVM.

Gao et al. [41] is used CIE XYZ transform in LCH spacing for segmentation and the main weakness of this method is its chromatic-adaptation transform, which is called Bradford transform. FOSTS model is then applied for shape analysis. Recognition process is performed by comparing the 49-dimensional vectors representing a current image with template vectors stored in the database that has been classified into several color/shape subgroups with an accuracy of 95%. Li et al. [33] is used HSI transform and fuzzy shape recognizer for detection and reorganization. The performance of the research has been classified into three categories; sunny, rainy and cloudy weather. Grahams scan algorithm is presented in order to calculate the convex hull, then it is passed to the fuzzy shape recognizer to verify and recognize. An example of the segmentation process in sunny weather of a partially occluded sign can be seen in Fig 2.

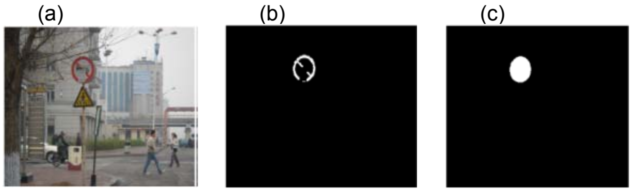

Fig.2. Segmentation process of partially occluded sign [33]

Eigen Vector Gradient Orientation and Karhunen-Loeve transform is used by Gonzalez-Reyna et al. [30] which is efficient in detecting blur sign. Eigen vector algorithm is also invariant in various lighting condition, noisy background and different viewing angle. 3D reconstruction method is specially modified method for detection damaged and partially occluded signs used by Soheilian et al. [42]. Fitting ellipse method is used for extracting ROI then Template matching is applied for texture analysis. After that, 3D reconstruction method is implemented to recover and recognize the sign. Khan et al. [43], extracted the color feature using Gabor filter and Joint Transform Correlation (JTC) is applied which has an excellent discrimination ability between object and non-object. This system is also invariant in rotation, transformation, scaling and viewing angle. An example is presented in Fig 7. MSER based HoG is used by Greenhalgh et al. in [29] whose main advantage is robustness in variable lighting, blurring and fading effect. AdaBoost method is used by Huang et al. [44], which is fast also useful to detect blur and faded signs and also in various lighting condition. In [44], for the Adaboost training, for positive and negative samples 925 images with speed limit signs and 2048 random images with no road sign are used respectively with an accuracy rate of 94.5%.

All the issues stated above needed to be considered while developing an effective TSDR system. The popular methods among the researcher have different drawbacks that reduce the efficiency of the system. Greenhalgh et al. [29] uses Hough Transform whose main drawback is dependency on input data and high processing time. For improving the system efficiency and robustness in various environmental condition, Dr. Kang-Hyun Jo and his groups are working for several years [45–47]. Combination of Shifted Filter Responses (COSFIRE) is introduced by Azzopardi et al. in [48] with a classification rate of 99.48%. Yang et al. [49] is used SIFT matching based algorithm for classifying damaged and broken signs. Further research should be needed for applying an effective TSDR system in the real-time environment. Table 1 showed some combinational techniques that improve the efficiency of the system by minimizing these issues.

Table 1. Comparative Studies between Different Methods

Ref.	Methods	Variable lighting	Blurring and fading	Multiple appearance of sign	Damaged sign	Partial obscured sign	Fast algorithm for Real-time	Motion Blur effect	Rotation, translation, scaling	Noisy background	Viewing angle
[29]	MSER based HOG + Decision tree	√	√	√			√				
[30]	Gradient Orientation + Karhunen-Loeve transform	√	√	√						√	√
[36]	Genetic Algorithm + Probabilistic NN	√	√				√			√	
[16]	adaptive shape analysis+ Probabilistic NN	√					√			√	
[37]	YCbCr + Image Normalization+NN	√	√				√			√	
[38]	SVM	√	√				√		√		√
[39]	Haar like features + SVM			√		√		√			√
[40]	Hough based SVM	√				√	√		√	√	√
[41]	CIE XYZ transform in LCH spacing + FOSTS Model	√	√	√						√	
[33]	HSI Transform + Fuzzy shape recognizer			√		√			√		√
[43]	Gabor Filter + Joint Transform Correlation			√		√			√		√
[49]	SIFT matching + SVM	√								√	
[44]	AdaBoost + CHT	√	√	√			√				
[42]	3D re-construction method				√	√	√				

Mogelmose et al. in [50], Mathias in [51], Fu et al. [52], Nguwi et al. [53] and Mammeri et al. [54] do related review on TSDR system. A brief review on various segmentation methods are presented by Gomez-Moreno et al. in [55]. For inner text detection from the extracted ROI of the system Gonzalez et al. [56] is developed dynamic dictionary based algorithm for a limited geographical area using a reverse geo-coding service. In our paper, we mainly focused the research trends in the field of developing efficient TSDR system. A brief timeline of the research is given including some recent problems that have been face by the researchers.

Conclusion and Suggestions

The main objective of this paper is to analyze the key direction of the field of automatic traffic sign detection and recognition. In this manuscript the overview of the research in the field of Automatic TSDR system is provided with some current issues and challenges and the respond of the researchers are also given. After assessing a huge number of paper, development in the field of Automatic TSDR system has been categorized into four major stages namely, early stage, intermediate stage, saturation period and modern age. We previously discussed the stages in the following sections and detailed comparative studies of the existing methods are also presented.

Current state-of-art, no human-machine interactivity is observed which can be a part of future research as it is very necessary for an efficient ADAS system. Another key problem is availability of public database which is also needed to be solved. There are some databases that are publically available but still not widely used and only covered the Vienna Convention-Complaint. For future research, some combinational method can be introduced to minimize especially the reliability factor as well as other issues for real-time application. In addition, traffic sign can be represented by GPS of RFID for accurate recognition. Moreover, for improving driver safety, inter-vehicle communication through RFID or Sonar applied while running on street.

The overview of the research, the comparative study and issues that are presented in the field of automatic TSDR in this paper with some future suggestion will hopefully lead to develop robust and efficient TSDR system because of its enormous range of applications.

Acknowledgement

This project was supported by Universiti Kebangsaan Malaysia under the grant number: UKM- DIP-2012-03.

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