A Study on Automatic Recognition of Road Signs

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***Abstract*— An automatic road sign recognition system identifies road signs from within images captured by an imaging sensor on-board of a vehicle, and assists the driver to properly operate the vehicle. Most existing systems include a detection phase and a classification phase. This paper classifies the methods applied to road sign recognition into three groups: colour-based, shape-based, and others. In this study, the issues associated with automatic road sign recognition are addressed, the popular existing methods developed to tackle the road sign recognition problem are reviewed, and a comparison of the features of these methods is given.**

***Keywords*—road sign, detection, identification**

I. INTRODUCTION

Road signs are used to guide drivers for direction, and to warn them of any special road condition. They provide important visual information that can help the drivers operating their vehicles in a manner that enhances road safety. A driver may not however notice road signs under adverse road condition. Failure to notice, or disregard of road signs may directly or indirectly contribute to some road accidents [1]. The occurrence of these accidents can be reduced using an automatic road sign recognition system that can alert the driver.

The objectives of an automatic road sign recognition system are to detect and classify one or more road signs from within live colour images captured by a camera. The system attempts to develop an on-board warning system to alert the driver of the approaching important road signs early enough to refrain road accidents from happening. It can form part of a driver assistance system which is a development in the field of on-board systems for smart vehicles [2].

Developing a road sign recognition system is a challenging vision task. There are a number of important issues that need to be addressed. These issues are highlighted below:

- Lighting condition is a very difficult problem to regulate. The strength of the light depends on the time of the day and season, and also on the weather conditions. The weather can be sunny, cloudy, rainy or etc. Outdoor lighting conditions vary from day to night and may affect the colour appearance of road signs within images. In addition, road sign patterns within images can be affected by shadows from surrounding objects. A picture of poorly illuminated road sign is shown in Figure 1(a).

- Images of road signs often suffer from blurring effect due to vibration of moving vehicle. The road sign extraction process in this case is difficult; it requires an additional image deblurring procedure prior to extraction.

- The direction of sign's face is not always ideal. Therefore, sign shape and pattern within an image can be affected due to the viewing angle.

- The paint on signs also deteriorates with time. Colours on road sign may fade after a long exposure to the sun and rain. Paint on signs may even be peeled off.

- Signs may be clustered. Multiple road signs may appear one over/beside the other. Figure 1(b) shows four road signs appearing side by side.

- Signs do not always have a perfect shape; some may be torn by storm or tilted due to pouring rain. Figure 1(c) shows an example of tilted sign.

- A significant problem with sign detection is related to the variation in scale, signs get bigger as the vehicle moves towards them.

- Even if the shape of interest is identified, it can be confused with other similar shapes of man-made objects such as commercial signs and building windows.

- Obstacles, such as tree, street lamp, buildings, traffic lights, vehicles and pedestrians, may partially occlude road signs that affect the performance of shape-based detection.

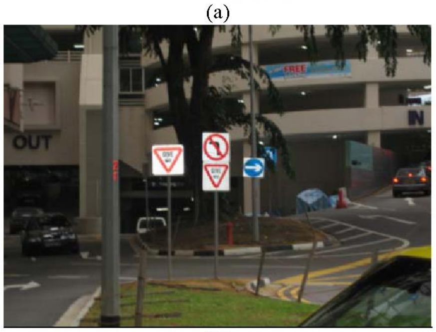
- The characteristics of the image acquisition system have implications on the quality of colour images captured.

These issues that are often unavoidable are the reasons why this topic is interesting, challenging, and worth researching.

According to Paclik [3], the first work on automated road sign recognition was reported in 1984. Since then, a number of methods have been developed for road sign detection and identification. A number of research groups have been developing solutions for road sign recognition. For example, the Image Recognition Laboratory at the University of Koblenz-Landau [4] which has developed a real-time traffic sign recognition system [5]. The performance is reported to be 98% correct recognition of the road signs, and it processes three images per second. Also, the Intelligent Systems Lab in the Carlos III University of Madrid has developed the Intelligent Transportation Systems [6] that can even predict and avoid accidents that could not be controlled by the driver.

Various researches have proposed various solutions to improve the efficiency of the automatic road sign recognition system. In general, most existing solutions include a detection phase and a classification phase. In the detection phase, the system searches for road signs within an image. In the classification phase, the system evaluates the regions found by the detection phase and identifies the signs. A road sign is distinct in its colour, shape, and pattern. It is designed to offer its basic meaning through the combination of these three properties. Therefore, most of the solutions rely heavily on these features of road sign. We put them into three groups: (i) colour-based, (ii) shape-based and (iii) others. The corresponding approaches are presented in the following sections.

(a)



(b)

(c)

Figure 1. Examples of road-sign images containing variations that make detection and recognition difficult: (a) poorly illuminated, (b) cascaded, and (c) tilted road signs.

II. COLOUR-BASED APPROACHES

Colour is the most important and significant visual feature in road sign. The main colour in road sign is chosen such that driver can notice it easily. Most existing road sign recognition systems include colour segmentation process that extracts out the coloured road-sign objects from the background for recognition. The colours that are used in road signs are regulated by different countries and are often simple primary colours (red, green, or blue) with the exception of yellow, a secondary colour. Colour is also regulated for the tint of the paint that covers the sign, which should correspond, with a tolerance, to a specific wavelength in the visible spectrum [7].

The main issue with the colour-based approaches is the outdoor illumination that might affects the colour acquired by the imaging sensor. Most colour-based techniques run into problems when the illumination source affects both the image intensity and colour. This is the main reason why many researchers have tried to come up with algorithms for separating the incident illumination from the colour signal perceived by the imaging sensors [8].

Colour-based detection methods aim at segmenting out the typical colours of road signs in order to provide a region of interest for further processing. Several widely used techniques on colour-based recognition are summarised below:

- *Colour Thresholding Segmentation*: This is one of the earliest techniques used for segmenting digital image [9]. Thresholding can be done by classifying pixels of an image into road sign pixels or background (non-road-sign) pixels. By matching a certain level, a pixel is called a road sign pixel if its colour is close enough to a reference colour, if not it will be considered as a background pixel. The literature in [10] and [11] illustrate the colour thresholding in detection phase.

- *Dynamic Pixel Aggregation*: This is another approach of colour segmentation. This method has been implemented successfully by Vitabile et al. [12], whose colour segmentation process is performed by introducing a dynamic threshold in the pixel aggregation process on HSV colour space. The dynamic threshold allows the reduction of hue instability in real scenes depending on external brightness variation. The segmentation rate in [12] is on the high end, ranges between 86.3% ~ 94.6%.

- *HSI/HSV Transformation*: The image captured by camera is represented by its Red-Green-Blue (RGB) value, which can be transformed into HSI value. In HSI colour space (see Figure 2), chromatic information is represented by the hue coordinate, and intensity coordinate captures varying light conditions. Also, HSI colour space is very similar to human perception of colours [17]. The HSI system encodes colour information by separating out an overall intensity value from two values encoding hue and saturation to make it more immune to lighting changes. Henry et al. [19] implemented this approach with 95% of correct detection in HSV colour space.

- *Region Growing*: The approach starts with a seed pixel, then expands it and group pixels of similar colour affinity together. It can be done in HSI colour space. As it requires initial seed and ends till a criterion is met, it may run into problem when its initial and ending criterion are not satisfied. Refer to [18] and [20] for its actual implementation.

- *Transformation Based on CIECAM97 Mode*l: This approach first converts the RGB space to the CIE's standard XYA space. The lightness, chrome, and hue (LCH) are then obtained using the CIECAM97 colour appearance model. The shortcomings of this approach is that object with similar colour as road sign could get segmented. Both [8] and [21] achieved high detection rate of above 90%.

- *Colour Indexing*: This is a straightforward, fast and efficient method. Comparisons for the coloured objects of two images are done by comparing their colour histograms [7]. Colour histogram is used to index the image and store into the database. The potential issue is its computation will increase greatly in complex traffic scenes. More details on this approach can be found in [13], [14], [15] and [16].

(a) (b)

Figure 2. Example of RGB and HSI representations: (a) RGB and (b) HSI.

III. SHAPE-BASED APPROACHES

Shape, being an important attributes of road signs, can be used for road sign recognition. Shape detection does not require colour information. However the selection of a scheme for the detection of road signs based on their shapes will have to address more issues than their colour as described in Section I. For example such issues as road signs in cluttered scene, imperfect shape, object occlusion, as well as variance in scale and size, make the detection task very challenging.

Shape detection requires robust boundary detection or matching algorithm to detect the relevant shapes. This becomes difficult when the road sign appears relatively small in the image, a situation that often occurs in low resolution cameras. Moreover even if a shape of interest is identified, it can be confused with several other shapes of man-made objects such as commercial signs and building windows [22]. However, shape detection is more robust to changes in illumination conditions as it detects shapes based on edges or boundary, and will efficiently reduce the search for a road sign regions from the whole image to a small number of pixels [23]. The common approaches based on shape are:

- *Hierarchical Spatial Feature Matching (HSFM)*: This approach is used to search for the geometrical shapes within an image of a traffic scene (see Figure 3), which may include some road signs. The detection algorithm generates a list of regions where some geometrical objects resembling road signs have been found, the list is then passed to the classification module. [24]. It works for grey-level input traffic scene image.

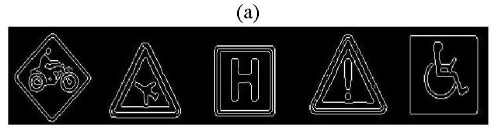
- *Hough Transform*: Hough transform is a technique, which can be used to isolate features of a particular shape within an image [26]. Because it requires the desired features be specified in some parametric form, the classical Hough transform is most commonly used for the detection of regular features such as lines, circles, etc. A generalised Hough transform can be employed in applications where a simple analytic description of a feature is not possible. Its advantage is that it is tolerant to gaps in feature boundary descriptions and is relatively unaffected by image noise. Hough transform is however computationally complex and memory hungry [23] that makes it not an ideal choice for road sign detection where speed is of utmost important.

- *Template Matching*: This method is mainly for classification phase. All sign shapes to be recognised are stored in a database. Each potential sign is normalised in size and compared with every template of the same shape. Yves et al. [28] introduced a worth noting template matching encoding that allows different templates to be combined according to the embedded colour information. With this encoding, a template is constructed for an object, and a correlation computation can be defined, which serves as a measure for computing matches between the templates. The method is fast and can be easily modified to include new classes of signs. It has been implemented successfully in the classification phase of [29] and [30] with >90% hit rate.

- *Similarity Detection*: This detection method is performed by computing a similarity factor between a segmented region and set of binary image samples representing each road sign shape. The method assumes that both sampled and segmented image have the same dimensions [31]. Vitabile et al. [31] make use of both colour and shape analysis for detection, and this similarity detection is done in the shape analysis phase. The segmentation hit rate is in the range of 86.3% ~ 95.7% with triangular shape giving the lowest hit rate.

- *Distance Transform Matching*: This technique uses a template hierarchy to capture the variety of object shapes; efficient hierarchy can be generated offline for given shape distributions using stochastic optimisation techniques [32]. Online, matching involves a simultaneous coarse-to-fine approach over the shape hierarchy and over the transformation parameters. It is capable of detecting objects of arbitrary shapes, which is an advantage over other techniques when dealing with non-rigid objects. Its limitation is that matching remains dependent on a reasonable contour segmentation. Its advantage is that the resulting similarity measure is smoother as a function of the template transformation parameters. It also allows more variability between a template and an object of interest in the image [32].

(a)



(b)

Figure 3. The HSFM approach: (a) input, and (b) resultant images.

IV. OTHER APPROACHES

Apart from the colour-based and the shape-based approaches, a few other commonly used methods exist are described below:

- *Decision Tree*: By making use of the gray-level features computed on histogram, projections and simple spatial moment invariants, decision can be made to recognise particular road sign [23].

- *Space Variant Sensor Window*: By placing a sensor window on the road sign centre, it is then able to recognise road signs, invariantly with respect to viewing and environmental conditions. The closer the sensor window is to the road sign centre, the quicker it gets recognised. Road sign centre is the chosen position because for most traffic signs the geometrical centre is also the centre of information content. References [8] and [21] experimented this approach with hit rate >85%. In [8], the space-variant sensor recognition forms parts of a biological model, the Behavioral Model of Vision (BMV).

- *Genetic Algorithm*: This algorithm can be used to search for traffic sign in a scene image. The image is matched by giving the gene information [33]-[34]. The gene of individuals can be represented by expression using a set of equation to determine its characteristic.

- *Histographic Recognition*: The histogram of road sign extracted from region of interest can be analysed to determine if any sign of interest is presented in the image [35]. The histograph is obtained by overlaying a mask over the image. Estevez et al. [35] reported a recognition rate of 50% in the literature.

- *Nearest Neighbour Classification*: This is the most straightforward and classic type of classification. An image in the test set is recognised by assigning to it the label of most of the closest points in the learning set [36]. All images are then normalised to certain value. The image in the learning set that best correlates with the test image is then the result.

- *Neural Networks*: Neural networks are well known for its powerful classification capability. When used in road sign classification, neural networks can be trained to recognise road signs' features within a region of interest. The commonly used models in road sign recognition are Multilayer Perceptron (MLP) network, Radial Basis Network (RBF), Backpropagation network, etc. Neural Networks can be used to train specific colour, shape, and pictogram. KellMeyer et al. [37] not only used Neural Networks for classification, but also colour segmentation. Neural Networks are being implemented in [10], [11], [12], [29], [37], [38] and etc.

V. DISCUSSIONS

Various commonly used techniques on road sign recognition have been presented. Some of these techniques can be used with others to realise a hybrid recognition system. A comparison of different features as well as performances of the existing techniques is presented in Table 1.

Comparing to colour-based recognition, shape-based recognition faces more limitations as addressed Section III. However, the shortcomings of colour-based recognition such as weather conditions and faded colour on road sign can be compensated through the use of shape-based recognition giving more superior performance.

For colour-based recognition, most approaches can operate considerably fast except colour indexing. Even though colour indexing can segment an image when the road sign is slightly tilted or partially occluded, its computation time increases greatly in a complicated traffic scenes. Hence, colour indexing is not ideal for real-time implementation.

Camera captures images in RGB colour format of which is not suitable for image segmentation as the colour information varies greatly under different weather condition. Often it is transformed into other colour space to like HSI, XYA space for processing. However, these transformations may become expensive in hardware realisation. Whilst, the Colour-Thresholding is easy, it may not be robust when the weather is poor or when the paint on road sign is faded.

The slow computation time of Hough Transform is a disadvantage, as it makes the method improper for real-time implementation. Template matching is popular but additional techniques need to be used with it to compensate for the imperfect sign shape problem. Similarity detection is like the Colour Thresholding in colour-based, simple and straightforward. However, this method may not give reasonable hit rate.

In other recognition category, the Space-Variant Sensor Window takes about 0.3~0.6 seconds to recognise which is quite fast. There are a few teams of researcher focusing purely on this approach. Placement of sensor window onto the road sign centre position is the determining factor of the hit rate.

Neural Networks classification is popular amongst pattern recognition applications; road sign recognition makes no exception. As shown in Table 1, neural network approach has the most number of references, and yet there are several more that have not been included. The recognition rate varies quite significantly (55% ~ 100%), this could be due to how well the networks are trained, and what network architecture are employed. The networks that achieved the highest hit rate [12] makes use of feedforward MLP Neural Networks. Neural networks are more adaptable to changes, and more flexible. Growing number of experimental results prove their robustness, which makes them stand out from the rest of the techniques.

Some of the techniques are robust but computationally costly, while others are simple but unable to handle changes in road sign patterns. None of the existing approaches can be totally immune to the problems faced by road signs recognition system as pointed out in section I yet.

Considering Table 1, most results reported in the literatures are tested on static images only, and only few on video recordings. This shows that the road sign recognition techniques are not yet mature. Research in this field is important and useful; it certainly deserves wider attention.

VI. CONCLUDING REMARKS

A review of the popular existing road sign recognition research has been given in this paper. The review includes description of: (1) important issues associated with road sign recognition, (2) existing methods developed to tackle the road sign recognition problem, and (3) comparison of different features as well as discussions of performances of the existing techniques.

Table 1: Comparison of road sign recognition approaches

Name of Technique	Cat	Theory	Advantage (s)	Possible Issue(s)	Computational Cost	Ref	Developer Name	Dev Yr	Performance
Colour Thresholding Segmentation	C*	Compare the colour properties to a set of values range and decide which category this pixel belongs to.	Simple		220ms detection time PC486 33MHz	[10] [11]	Escalera et al. Ghica et al.	1997 1995	
Dynamic Pixel Aggregation	C*	Colour segmentation is performed by introducing a dynamic threshold in the pixel aggregation process on HSV colour space.	Reduce hue instability.	Performance drop when images are characterised by predominant set of sign pixels whose co-ordinates fall in HSV unstable areas.		[12]	Vitabile et al.	2001	86.3% ~ 95.7% segmentation hit rate, tested using 620 outdoor images. Running on pentium 3 550MHz under linux environment.
HSI/HSV Transfor-mation	C*	The HSI colour space can be transformed from RGB using various equations.	Segments adversely illumina-ted signs	Hue is not suited for grey-level axis		[18] [19]	Nicchiotti et al. Henry et al.	1994 2001	Detection rate=95% (524 out of 540 correct detection).
Region Growing	C*	Started with a seed pixel, then expand it and group pixels of similar colour affinity together. It can be done in HSVspace.		Initial seed selection and ending criterion may not be met		[20] [18]	Priese et al. Nicchiotti et al.	1993 1994	>84%
Transfor-mation base on CIECAM97 model	C*	First converts RGB space to CIE standard XYA space. The lightness, chroma, and hue (LCH) are then obtained using CIECAM97 model.	It estimates colour very close to viewer.	Objects with similar colour as road sign could get segmented		[21] [8]	Shaposhnikov et al. X. Gao et al.	2002 2002	>90% detection hit 90% on sunny days
Colour Indexing	C*	Comparisons for the coloured objects of two images are done by comparing their colour histograms, regardless of the objects' orientation or partial occlusions [7].	Straight-forward fast efficient	The computation time will increase greatly in complex traffic scenes		[13] [14] [15] [16]	Swain et al. Swain et al. Funt et al. Haeley & Slater	1990 1991 1995 1994	
HSFM	S*	Generates a list of regions where some geometrical objects resembling road signs have been found, the list is then passed to the classification module.	Indepen-dent of road sign colour.			[24] [27]	Pavel & Jana Pavel et al.	2000 1995	Promising for real time implementation, but no detail detection test result shown in the reference.
Template Matching	S*	All signs to be recognised are stored in database. Each potential sign is normalised size and compared to every template of the same shape.	Fast Can be easily be modified toinclude new classes of signs	Imperfect road sgin shape may pose a problem.	130ms T* on 1.4GHz PC, 512MB RAM	[28] [29] [30]	Yves et al. Ohara et al. Torresen et al.	2001 2002 2004	85% ~ 95.6% recognition rate. >95% recognition rate 90.9% recognition rate
Similarity Detection	S*	Signs shape detection is done by computing a similarity factor between a segmented region and set of binary image samples representing each road sign shape.	Straight-forward			[31]	Vitabile et al.	2001	86.3% ~ 95.7% detection rate.
Distance Transform Matching	S*	It uses a template hierarchy to capture the variety of object shapes.	Allows dissimilarit y between object and template.	Matching may remains dependent on contour segmenta-tion.		[32]	Gavrila	1999	> 95% detection rate tested on 1000 static images.
Space-Variant Sensor Window	O*	By placing a sensor window on the road sign center, it is then able to recognize road signs.	Invariant with respect to viewing	Accuracy degrades if sign center found is not the actual center.	0.25~0.4s T*, P233 0.35~0.6s T*,P3 400MHz	[21] [8]	Dmitry et al. X. Gao et al.	2002 2002	>85% success rate 88% ~ 90%
Genetic Algorithm	O*	Transform position & size of road signs into a no. of genes. After computation, the high-fitness genes were then assumed to represent road sign.	More immune to illuminatio n problems.		17ms T* P3 395MHz	[33] [34]	Aoyagi et al. Escalera et al.	1996 2001	
Neural Networks (NN)	O*	Train neurons to recognise colour, shape or pictogram on road sign.	fast - matching adaptable	Require large set of training data to train up good network	2min 30 sec T* 486/25MHz PC ~0.3s P4 1GHz 1.2s PC486 33MHz	[37] [29] [38] [10] [12]	Kellmeyer et al. Ohara et al. Chiung-Yao et al. Arturo &Miguel Vitabile et al.	1994 2002 2003 1997 2001	55%~86% hit rate (NN Classification) >95% of hit rate (Shape NN detection) Hit rate not reported, tested on various video sequences. 84%~100% tested on 620 static images.

C* : Colour-based recognition ; S* : Shape-based recognition; O* : Other recognition; T* : Total processing time (Detection + Recognition)

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