A Real Time Traffic Sign Detection and Recognition Algorithm based on Super Fuzzy Set

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Abstract

Advanced Driver Assistance Systems (ADAS) benefit from current infrastructure to discern environmental information. Traffic signs are global guidelines which inform drivers from near characteristics of paths ahead. Traffic Sign Recognition (TSR) system is an ADAS that recognize traffic signs in images captured from road and show information as an adviser or transmit them to other ADASs. In this paper presents a novel machine vision algorithm for traffic sign recognition based on fuzzy sets. This algorithm is a pipeline consists of multiple fuzzy set that create a fuzzy space here called Super Fuzzy Set (SFS). SFS helped to design a flexible and fast algorithm for recognizing traffic signs in a real-time application. Designed algorithm was implemented in computer-based system and checked on a test car in real urban environment. 83.34% accuracy rate was obtained in real-time test.

Keywords: *Advanced Driver Assistance Systems, Traffic Sign Recognition, Super Fuzzy Set, Vision Algorithm.*

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1. Introduction

Driver assistance systems help drivers to increase driving quality. Traffic sign recognition (TSR) system is an intelligent driver adviser that provides road information by extracting the meanings of traffic signs. Traffic signs are visual information that consist of standard shapes and symbols combination. Artificial intelligence methods improve image processing and machine vision algorithms for extracting the traffic sign's meanings.

In recent years, image processing and machine vision algorithms have been developing for traffic sign detection and recognition [1,2,3]. Extracting traffic signs' meanings is divided to three primary stages. The first stage in all image processing algorithms is preprocessing. Second stage is detection, that seeks sign region in an image. In the third stage, the algorithm looks in the detected regions to find traffic signs and extract their meanings.

A soft computing method witch was used mostly in artificial intelligence sciences is fuzzy logic [4]. It benefits from the human's experiences to make decisions for different processes. In TSR systems based on image processing, many researchers have been using fuzzy sets in their algorithms. In an image, standard colors of traffic signs are interest to find candidate regions. In [5] and [6], fuzzy sets were used in preprocessing stage for color segmentation. But during the day environmental illumination varies. Change in the captured images brightness is a difficult challenge for segmentation algorithms. So a fuzzy inference method presented by [7] was used to evaluate the input image illumination conditions in order to apply appropriate preprocessing operations.

Making decision in detection and recognition stages is very important. Because a wrong decision in preprocessing stage will decrease only the algorithm accuracy, but a wrong decision in recognition stage will result in a failure in the algorithm. In [5], four kinds of traffic sign shapes are detected based on fuzzy inference system (FIS). Two Fuzzy ARTMAP Neural Networks with separate training sets trained in [8] for traffic signs detection and recognition stages. Also a fuzzy-neural technique based on back-propagation neural network (BNN) modeled in [9] and an adaptive neuro fuzzy inference system (ANFIS) presented in [10] for recognizing traffic signs were utilized. Chiang et al. were proposed a fuzzy adaptive-kernel-based learning vector quantization (FAKLVQ) approach for recognition stage [11].

FIS and neural networks combination methods base is on training approach. In this approach, machine learning [12] or neural network algorithms are training with sets of patterns. Neural network is not necessarily combined with FIS in TSR systems [13,14]. Support vector machine (SVM) is a kind of machine learning algorithms. It was used in [15] for detection and in [16] and [17] for traffic sign recognition. Other machine learning algorithms consist of nearest neighbors and decision trees are used in [18] and [19] respectively.

Another method used in recognition stage is matching approach. Pattern-based matching approach needs a matching algorithm to compare input image with traffic signs patterns considered in data base [20,21]. The patterns generally have the form of either sequences or tree structures. Liu et al. recognized speed limit traffic signs with fuzzy template-based matching method [22]. Template consists of all sample pixels that have to be compared with input image. If recognition target has strong features, feature-based matching is a proper approach. In [23], discriminative features were used for traffic sign recognition.

In this paper a novel machine vision algorithm based on fuzzy logic will be presented for traffic sign recognition system. So first, the Super Fuzzy Set (SFS) approach and design the traffic sign recognition algorithm is described in three stages, preprocessing, detection and recognition. Then the results of implementation and practical test are described and compared with other researches.

2. Super Fuzzy Set Approach

Proposed intelligent algorithm for traffic sign detection and recognition consists of preprocessing, detection and recognition stages. Here has benefited FIS in most operations of each stage for making decision, but has not used traditional fuzzy sets. Image processing and machine vision operations are complex processes. So in this algorithm a multiple fuzzy sets called super fuzzy set (SFS) were designed here.

Figure 1 shows traffic sign detection and recognition algorithm diagram. The purple region is super fuzzy set. First, a fuzzy image from primary image by fuzzification operator was created. Then a fuzzy adaptive denoising algorithm clears unwanted pixels of fuzzy image. In a parallel process, edges of primary image were detected by Sobel algorithm. Edge image must convert to fuzzy edge image for entering the SFS. Then a logical AND operates on the final images of two parallel process. So edge pixels were removed from image and it is ready for labeling operation. In labeling operation, connected components that have same color mark as a label.

In detection stage, the aim is finding some traffic signs' primary features in extracted labels and canceling none traffic sign labels. So operational accuracy and velocity are increased in recognition stage. Beside color, standard shapes are good feature to detect traffic signs. In this paper, feature points method of invariant features [24] is used. Feature points match with candidates at feature points position operation to obtain appropriate data for detection inference engine. In feedback process a rotation and scaling operation designed to detect traffic signs at various space terms.

Candidates detected as traffic signs have to pass the recognition stage. In this stage like detection stage, feature points are extracted and conceded to recognition inference engine. For each candidate decision is made to recognize traffic sign concepts. Finally, SFS result was converted to a numerical variable by defuzzification operation.

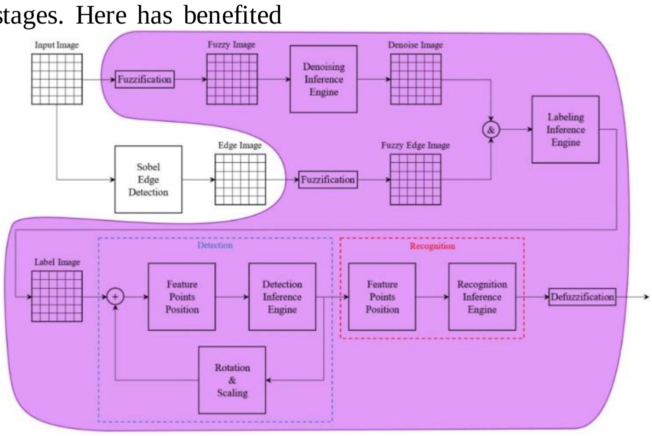

Fig1. Proposed algorithm diagram.

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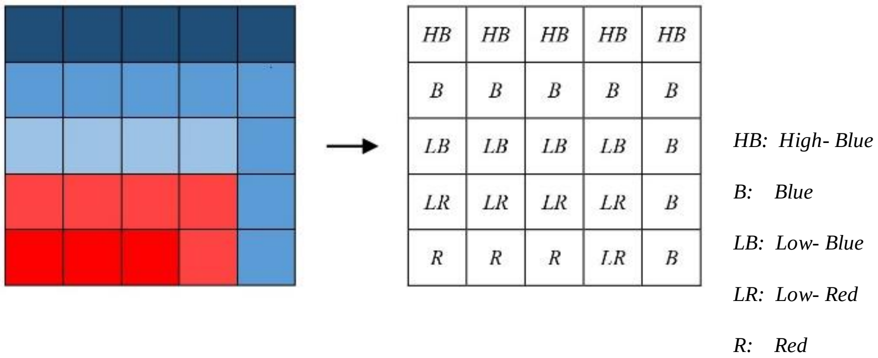

Fig2.. The meaning of fuzzy image.

Fig3. Sobel edge detection.

2.1. Preprocessing

Captured image from camera is in RGB format. First it is converted to HSV (Hue-Saturate-Value) space. In HSV space the illumination variation just efficacy on V parameter, but H is color parameter that must be processed here. Traffic signs have standard pure colors, so HSV space can help to detect them in environmental image. Also one parameter processing in HSV space increase process speed versus three parameters processing in RGB space for color segmentation operation [25].

A fuzzy color segmentation designed to collect interest colors from image. Fuzzy Image is output of this operation. In Fuzzy Image each pixel characterizes describe with linguistic variables. Fuzzy color segmentation is an entering gate to SFS. Figure 2 shows the meaning of Fuzzy Image.

H parameter is pixel color in HSV space. This parameter has all colors spectrum mapped on 0 to 360 degrees. Thus can create a fuzzy membership function for H parameter for color fuzzification. Some linguistic variables like “colorless” or “colorful” are described with S parameter membership function and some others like “bright” or “dark” can be described with V parameter membership function.

Fuzzy Image has some undesirable color pixels. They are consisted of single outspread pixels that must cancel with denoising operation. A fuzzy adaptive denoising algorithm designed to compare color of pixels in a 3×3 sliding window to making decision for color of central pixel.

After denoising operation, image is ready for labeling. But there are some traffic sign detection challenges in urban environment. One is background color similar to that of traffic sign. In this case, in fuzzy image a correct detection cannot be made. Because the created fuzzy image consists of some basic discrete colors. So a color spectrum in primary image, have single linguistic value in fuzzy image. Here Sobel edge detection algorithm [26] is used to confuse this challenge by extracting primary image edges showed in a parallel process path in Figure 1. Figure 3 shows a traffic sign and its edge image.

Sobel edge detection operate in numeric space. For entry the SFS it must fuzzify. Then a logical

AND operates to delete edge pixels from denoising image.

Final image is consisting of some connected components that create a shape in image. These connected components are extracted with labeling operation. Labeling operation looks in image for regions containing neighbor pixels with same color. Then assign a unique number as a label to a set of connected pixels. There are two methods for component labeling: Sequential and Recursive [27]. Recursive labeling method is used in present algorithm. After that detection stage is operating on labeled regions.

2.2. Detection

Feature based methods were usually used for object detection and recognition in machine vision [28]. Features are some unique properties of object that distinguish it from other same objects. Size, angle view, brightness, etc. of objects in different images always vary. So features chosen for detection and recognition must be useful in different situation. Generally, there are two kinds of features [24]. First, Local Features that include points, edges, etc. and second Global Features that include some methods like histogram analysis.

Interest Points method is used in detection stage of proposed algorithm. It is local features subset. This method considers a pixel in a color region as agent. Agent locations was selected by expert experience for use in propose fuzzy detection in SFS. In following, Detection operation steps will be described.

Extracted labels from Fuzzy Image have to check in detection algorithm. But all labels are not traffic signs. Before detection stage labels are filtered with low level and high level thresholds on total pixels in a label. Then they are filtered with dimensional ratio. Labels that passed these filters will be sent to detection stage.

Connected components must be check separately in detection algorithm. Geometric shapes of traffic signs are square, circle, triangle, hexagonal and diamond but in this paper square, circle and triangle were considered. In order to detect these shapes, 10 points were selected that are shown on Figure 4.a. Color linguistic value of each feature points makes an input for detection inference engine. Special compositions of feature points that are consider for desired shapes has been shown in Figure 4.b,c,d. For example, fuzzy rule for detecting triangle that used feature points in Figure 4.d is:

If C&F&H&I is Red & B&E&G&J is NOT Red Then Shape is Triangle with Red Rim.

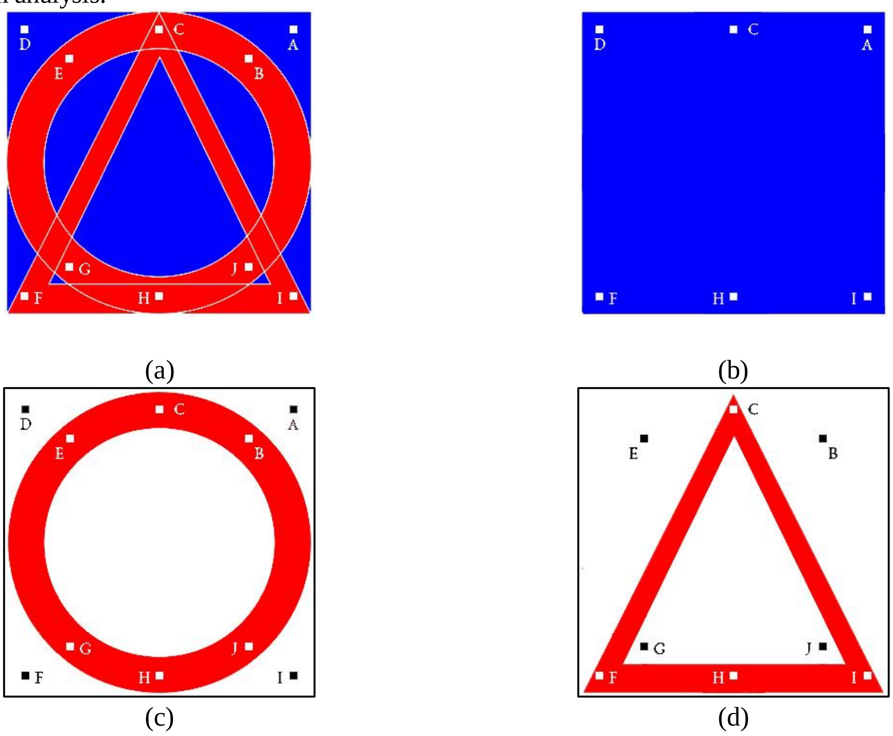

Fig4. Feature points selected for detection stage. a) All feature points. b) Square feature points. c) Red rim circle. d) Red rim triangle.

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Inputs A and D is not used in this rule. It means their values are not important in triangle detection.

Here, patterns dimensions are 41×41 pixels. Each point is stored by Polar coordinate system according to Equation 1 and 2.

$$r_A = \sqrt{{x_A}^2 + {y_A}^2} \quad (1)$$

$$\theta_A = arctan\left(\frac{y_A}{x_A}\right) \quad (2)$$

In equations, xA and yA are Cartesian coordinate of point A in pattern format, rA and θA are corresponding Polar coordinate of point A.

Figure 5 shows the schematic of detection stage. Feature Points Position operation is in relation with final image of preprocessing stage and Data Base. Polar coordination of feature points is stored in Data Base. Feature points Coordination is extracted from ideal patterns in laboratory conditions. But performance improvements of proposed algorithm in real environments needs to consider sign scaling and rotation. So Feature Points Position operation calculates the dimension ratio between pattern and candidate component in image. Then it scales feature points by varying the radius and extract the data of feature pixels. In most similar researches, Because of use fixed patterns, candidate segment of input image is adapted with pattern [29]. But in proposed intelligent algorithm, pattern and candidate segment are adapted by varying feature points data.

Each feature point Cartesian coordinate is restored by Equation 3 and 4.

$$x_f = x_{(mid)_{seg.}} + \left\{ k \left(\frac{x_{(max)_{Seg.}}}{x_{(max)_{Pat.}}} \right) r\, cos(\theta + \varphi) \right\} \quad (3)$$

$$y_f = y_{(mid)_{seg.}} + \left\{ k \left(\frac{y_{(max)_{Seg.}}}{y_{(max)_{Pat.}}} \right) r\, sin(\theta + \varphi) \right\} \quad (4)$$

Factor k is scale ratio due to φ degrees rotate of pattern around axis perpendicular to the image plane and limited to fixed frame. Values xf and yf are final coordinate of each feature point. Also terms Seg. and Pat. introducing candidate segment of image and pattern respectively.

Data of feature points are sent to Fuzzy Detection Inference Engine. This operation according to rules defined in Rule Base and inputs is making detection decision. If sign is not detected in process, pattern is rotated by feedback path operation. Fuzzy Rotation & Scale Inference Engine operation rotate the feature points by varying the angle. If square and triangle shapes rotate in a fixed frame (here 41×41 pixels) then their dimension will change. So the radius must scale too. Then candidate is checked with new r and theta ratio. continuance necessity of this loop is determined by Fuzzy Rotation & Scale Inference Engine operation.

2.3. Recognition

The recognition stage is final decision making stage in proposed SFS. It focuses on traffic signs character to extract their concepts. Proposed recognition algorithm is based on fuzzy logic and feature points method similar to detection algorithm. But here feature points coordinate and fuzzy rules are different. Also each kind of traffic signs needs a different set of feature points. Figure 6 shows the schematic of recognition stage.

According to Figure 6, Final Detection, r, Theta and candidate region detected as traffic sign in B&W format are inputs of recognition stage

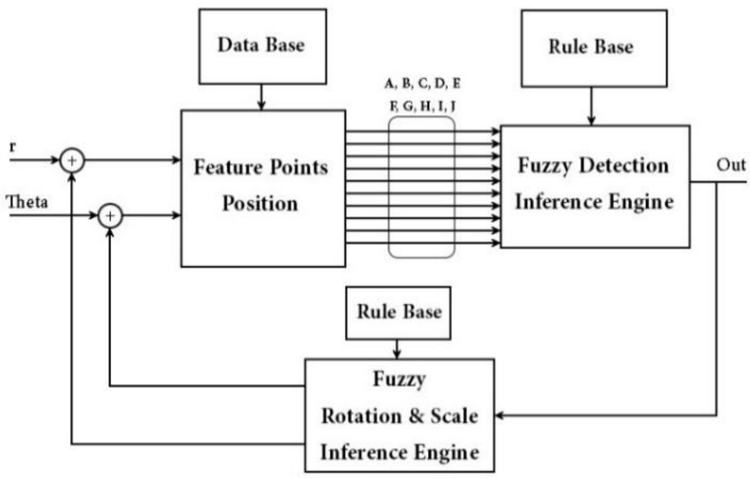

Fig5. Schematic of Detection Stage

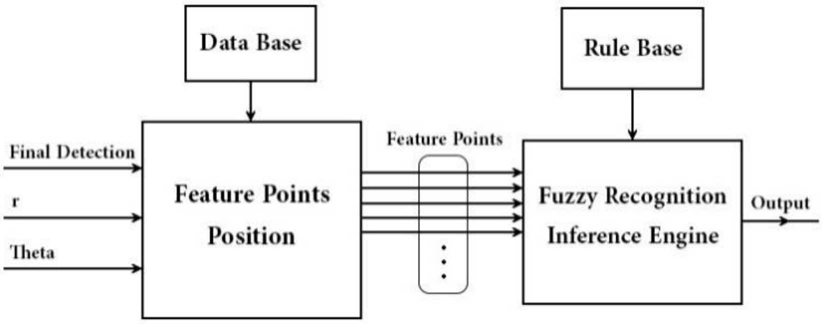

Fig6. Schematic of Recognition Stage

Fig7. Equipped trial car in AVCSLab.

. Final Detection is decision made in preview stage for each candidate. Also r and Theta correspond to rotation angle of traffic sign in image calculated in feedback of detection stage.

Feature Points Position operation in Figure 6 has different database of the same operation in detection stage. So this operation according to stage inputs and points polar coordinates stored in Data Base extract the color of feature points in candidate regions. Fuzzy Recognition Inference Engine makes final decision about concepts of traffic signs base on designed Rule Base.

3. Experimental Results

A system is collected to test and validate the proposed traffic sign recognition algorithm in real-time and urban environment. This system is based on software programming with OpenCV library. OpenCV was designed for computational efficiency with a strong focus on real-time applications [30]. Here an action camera in car-mode is used to capture images with a telephoto lens mounted on it. Figure 7 shows the trial vehicle and the camera mounted on it. This platform prepared in Advanced Vehicle Control Systems (AVCS) laboratory in K.N. Toosi University of Technology and used to test the proposed algorithm in real environment.

Figure 8 shows the results of algorithm steps. Figure 8**Error! Reference source not found.**.a is the original input image. It was captured from urban environment to test the algorithm. First some defined sampling points extract from image. Analysis of them helps to create adaptive contrast and brightness filters to enhance image against light variation. In this application, just Red, Blue and Black colors are interest. So color fuzzification operation discards unwanted colors and fuzzy rules defined for interest colors. Figure 8.b shows fuzzy image.

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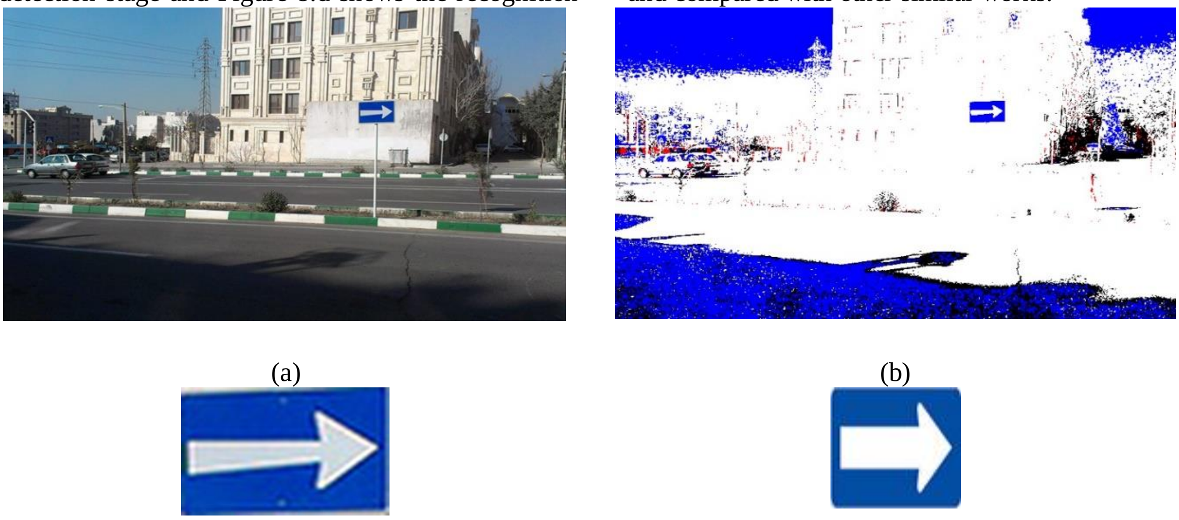
Membership functions Designed to create fuzzy image are shown in Figure 9.

Finally, recognition inference engine checks candidate regions to detect traffic signs. In sample, Figure 8.c shows the image region that cropped by detection stage and Figure 8.d shows the recognition result. It is a sample of patterns used to interest points election and design rules of recognition FIS.

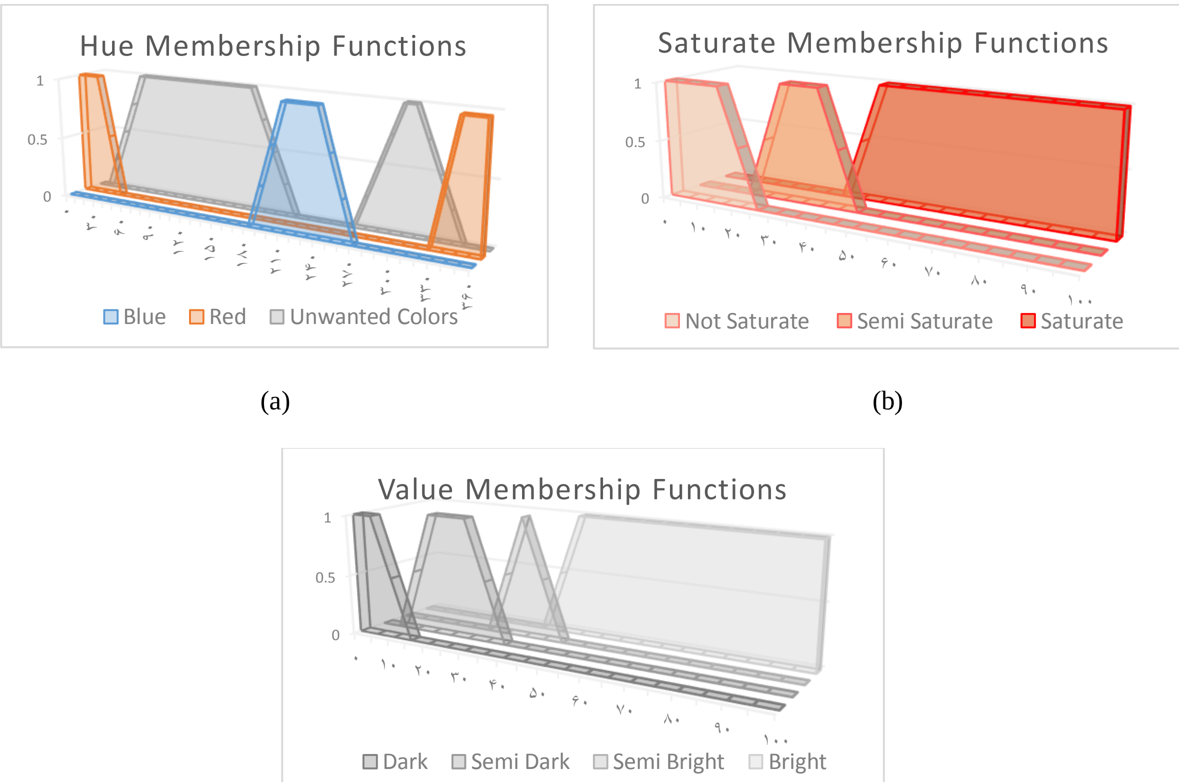
In real-time application, the system achieved 6 frames per second. It is an appropriate frame rate for urban environment. The result is shown in Table 1 and compared with other similar works.



(a) (b)

(c) (d)

Fig8. Algorithm Steps in Test. (a) Original RGB image, (b) Fuzzy Image, (c) Sign Region Detected and (d) Traffic Sign Recognized.



(a) (b)

(c)

Fig9.. Membership Functions of Fuzzy Inference System for Create Fuzzy Image, (a) Hue Membership Functions, (b) Saturate Membership Functions, (c) Value Membership Functions.

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Table 1. Comparing results with other works

	Correct Recognition	Incorrect Recognition	Signs Missed by System
Sindha [31]	92.08%	3.96%	3.96%
Kardkovacs [32]	78.4%	12.6%	3%
Proposed Algorithm	83.34%	5.55%	11.11%

4. Conclusions

In this paper, a novel algorithm based on Supper Fuzzy Set (SFS) is presented in a machine vision system. SFS has general application in control and making-decision systems. Here it is used to design a traffic sign recognition system to analyze images captured from real road environment.

Designed algorithm has been implemented and checked with a test car in a real-time scenario and real environment. Results show the suitable functioning of the system compared with similar researches.

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