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Soft Edge Detection by Mamdani Fuzzy Inference of Color Image

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***Abstract*— One of the most common image operation analyses is the edge detection technique. Edge detection is used for shaping the edge of an image. Also, it is used for enhancing images. This paper presents a new approach to detecting the edge of color image using the Mamdani fuzzy inference classifier based on the Fuzzy Set Membership Function (FSMF). Here, Gaussian Curve Membership Function (GCMF) is used as a FSMF. GCMF is used for each class to assign that class to each pixel. In this approach, two windows/filters are used in size (1x2) and (2x1). Several standard color images are used to test our proposed algorithm (City, Jelly_cc11, Baboon, Lena, and Peppers). In order to parametric evaluation of selected images, Peak Signal Noise Ratio (PSNR) and Mean Square Error (MSE) are considered. However, the performance of our proposed algorithm compared with other well-known approaches (Canny, Prewitt, and Sobel) is somehow very similar but significantly faster.**

Keywords— ***Fuzzy Inference, Edge detection, Color image edge detection, Mamdani fuzzy inference, Gaussian curve membership function.***

I. INTRODUCTION

In the recent few years, Soft Computing (SC) to solve real-world image processing problems has been increasing rapidly. SC is a field that involves a lot of significant theories like neural networks, evolutionary computation, genetic algorithms, and Fuzzy Logic (FL) [1]. This paper is concerned with developing a FL rules-based algorithm to detect an image edge. FL is considered a powerful technique for modelling uncertainty in the practice of images [2]. FL is a decision in an inaccuracy environment and the ambiguity and lack of completeness. Fuzzy methods process the classes whose boundaries are elusive and uncertain. Fuzzy classes specify a degree of membership intermediate between one and zero [3]. Edge pixels - also known as boundary pixels, can be defined as a set of pixels with the same region of an image that has one or more neighbors have a rapid change in gray level (or intensity level of color) pixels. One of the biggest problems in the Fuzzy Inference System (FIS) is the simulation technique [4, 5].

In this paper, we are concerned with developing new FIS rules with the ability to detect edges. At this point, to design an image's edges detector simulator, we develop FIS rules using a MATLAB environment and using a scanning filter as small as size (1×2) and (2×1) filter. Sixteen FIS rules are suggested to mark processed pixels as an edge (e), white (w), or black (b). See TABLE I. Additionally, the implementation of Gaussian noise removal as an intermediate and final level processing is considered.

However, the rest of the paper is divided into five sections. Firstly, the related works and the Mamdani FIS are discussed in section two. Secondly, section three explains the methodology of the proposed method. After that, the performance results are illustrated in section four. Finally, section five concludes the whole study.

II. RELATED WORK

Edge detection has been studied widely and used efficiently in several areas like enhancement of noisy images [6, 7], enhancement of satellite images [8], enhancement of x-rays [9, 10], enhancement of medical images [11], mapping of roads [12, 13], text detection [14], video surveillance [15, 16], and remote sensing image [17]. The extensively used edge detection techniques are the Canny [18], Sobel [19], Prewitt [20], Laplacian [21], Fuzzy logic [9], etc.

In [4], two gradients filters are combined– the high pass filter and Sobel operator, followed by the morphological dilation and FL. This method recognizes the edge based on different frame factors in the captured image. Furthermore, more than color space is applied while using a solo band for the process of edge detection. Also, another approach [22] based on a combination of Sobel operator with interval type-2 FL provides an edge with the capability to handle ambiguity in processing images. Although, the adaptive fuzzy local ternary pattern is used as an edge detector in [23]. Fuzzy C-means clustering detects an edge in MRI brain tumor images [24].

Originally, Mamdani FIS was used to synthesize a set of linguistic control rules from experienced human operators. The result of each rule in a Mamdani FIS is a fuzzy set. Generally, the Mamdani FIS is an intuitive system with a rule base that can be more easily interpreted and is well-suited to human input [25]. However, the Mamdani FIS is described in Fig. 1. Correspondingly, readers are recommended to see [26].

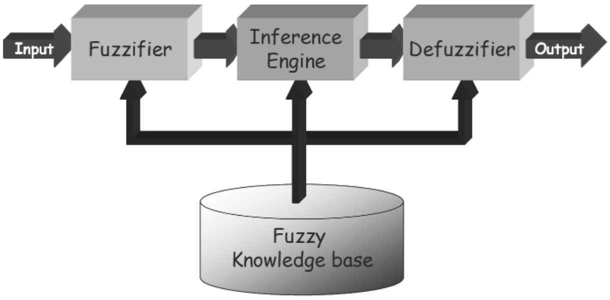


Fig. 1 Mamdani FIS.

III. Methodology

Our proposed system contains four stages. Firstly, enhance the image for better edge detection by (removing noise, adjusting the brightness, sharpening if required, etc.). Here, we remove the noise by applying Gaussian using two windows that are $\mathrm{Mask_x} = [-1\ 1]$ and $\mathrm{Mask_y} = \begin{bmatrix}-1\\1\end{bmatrix}$ so that all the edges can be detected accurately, and secondly, we extract the color channel of the input image. Thirdly, apply Mamdani fuzzy inference (MFI).

TABLE I
Fuzzy Sets Input and Output Variables

Input #1 = I1		**Input #2 = I2**	
Name	**Color**	**Name**	**Color**
Black	[0 0 255]	**Black**	[0 0 255]
White	[0 255 255]	**White**	[0 255 255]
Input #3 = I3		**Input #4 = I4**	
Name	Color	**Name**	Color
Black	[0 0 255]	**Black**	[0 0 255]
White	[0 255 255]	**White**	[0 255 255]
Output #1 = Out1			
Name	**Color**		
Black	[0 3 5]		
Edge	[130 133 135]		
White	[255 255 255]		

The main objective and advantages are precise edge detection and complexity reduction. Finally, In the parametric evaluation of selected images, Peak Signal Noise Ratio (PSNR) and Mean Square Error (MSE) are calculated and compared with state-of-the-art algorithms.

Subsequently, the architecture of the proposed system will be figured out in Fig. 2.

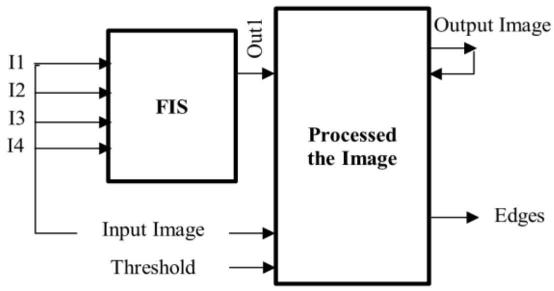


Fig. 2 Proposed system architecture.

A sample representation of the proposed FIS is shown in Fig. 3.

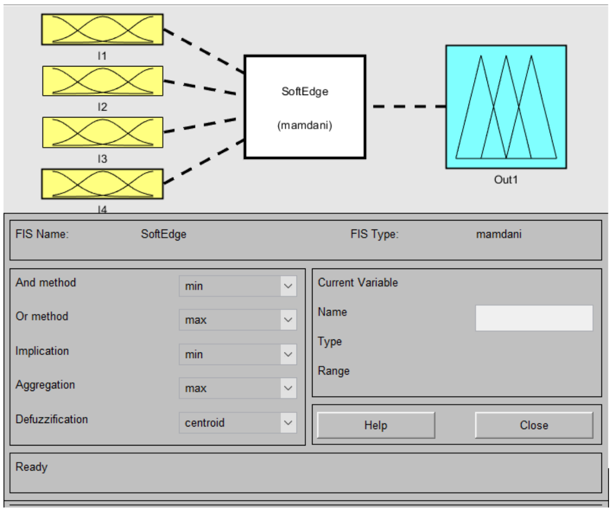


Fig. 3 Proposed FIS.

However, by applying the suggested FIS rules, which are declared in TABLE I, see Fig. 4:

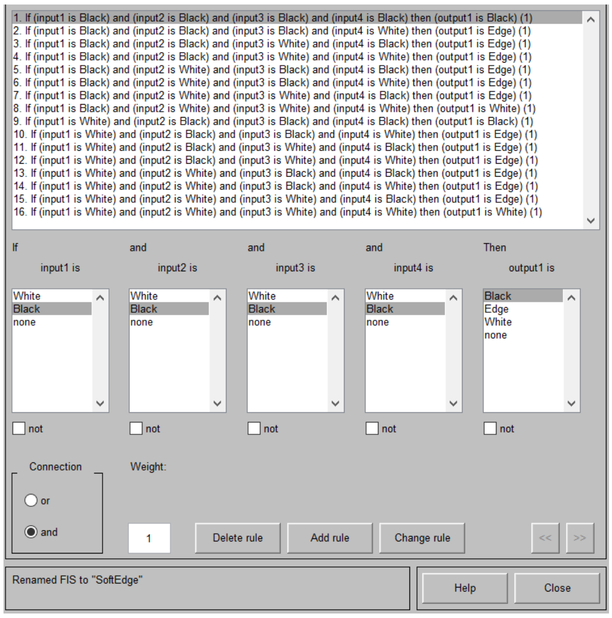


Fig. 4 Applying FIS rules.

Furthermore, we summarize the algorithm of the proposed method as follows:

Algorithm of MFI edge detection
Input: Color image
Output: Edge detection
Step 1: Select the input image Step 2: Remove noise using filters for better equality. Step 3: Apply the image enhancement technique to improve the c1uality of the image (histogram equalization). Step 4: sprouted bands (red, green, and blue). Step 5: for each band, apply two windows $\mathrm{Mask_x} = [-1\ 1]$ and $\mathrm{Mask_y} = \begin{bmatrix}-1\\1\end{bmatrix}$ Window to the image, a set of fuzzy logic conditions at a threshold value. Step 6: Get the edges detected from various directions at various threshold values:

1. If (Mask_x is zero) and (Mask_y is zero), then (I_{out} is white)
2. If (Mask is not zero) or (Mask_y is not zero), then (I_{out} is black)

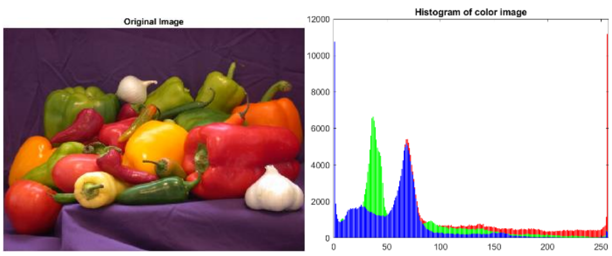
Step 7: Select the best among all the edge detected images.
Step 8: Final output of image with edges located precisely will be achieved

IV. RESULTS

In order to test our proposed method, we used a different color image (City, Jelly_cc11, Baboon, Lena, and Peppers). The performance of this approach is compared with a number of the most known edge detection techniques. It provides a better visual edge appearance and more distinct marked edges. It can be experimental that the output that has been produced by the MFI method has found image edges more clearly as compared to the ones that have been found with the most known edge detection algorithms. Consequently, the MFI rule-based system produces improved edge detection and has a comprehensive set of MFI conditions that support extracting a high-efficiency edge result. The first stage is image selection. In this stage, a particular image for which the edges are to be detected has to be selected, and the image will be separate the bands (red band, green band, and blue band) as shown in Fig. 5.

Fig. 5 Separate image bands (red, green, and blue)

The second stage is image enhancement by removing noise, adjusting the brightness, sharpening if required, etc. we used histogram equalization to adjust the image's brightness, as shown in Fig 6.



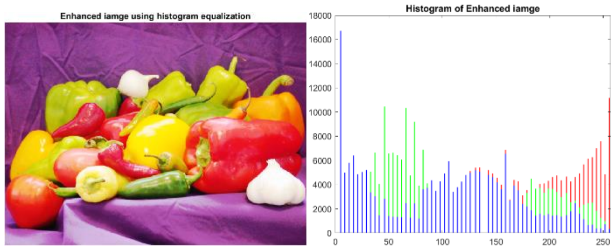


Fig. 6 Enhancement image by using histogram equalization

The third stage is the edge detection stage. In this stage, we applied MFI rules to each band of the input image. However, we are supposed to get an image with perfect edges and less noise when compared to other edge detection techniques, as shown in Fig. 7, Fig. 8, and Fig 9.

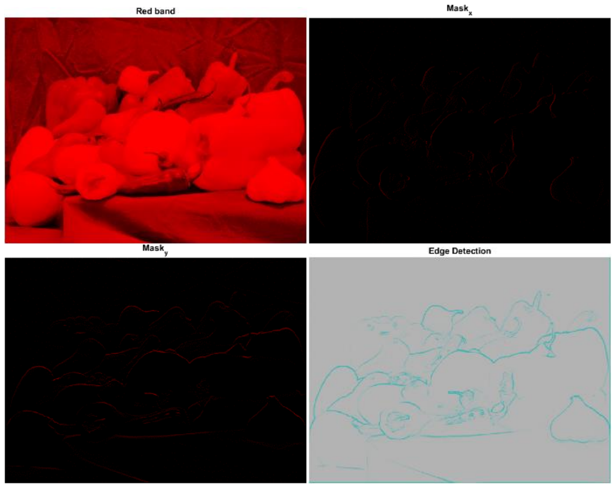


Fig. 7: Appy fuzzy logic on the red band

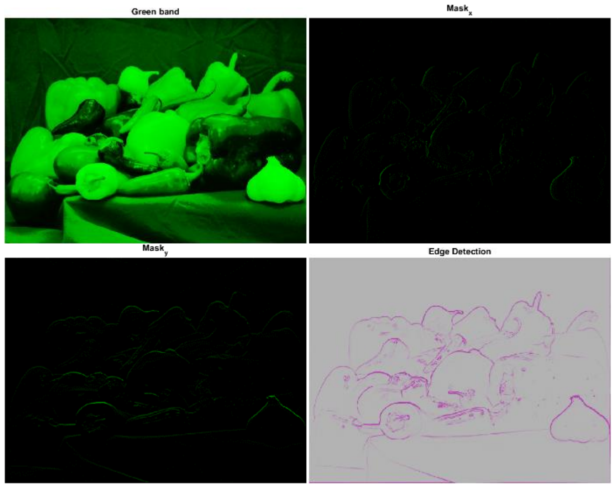


Fig. 8: Appy fuzzy logic on the green band

Applying MFI rules to the input image bands shows that the detected edge is free of noise and semi-perfect. Next, we applied the proposed method to the enhanced image. Fig 10 displays the detected edge of the input image after applying the proposed method.

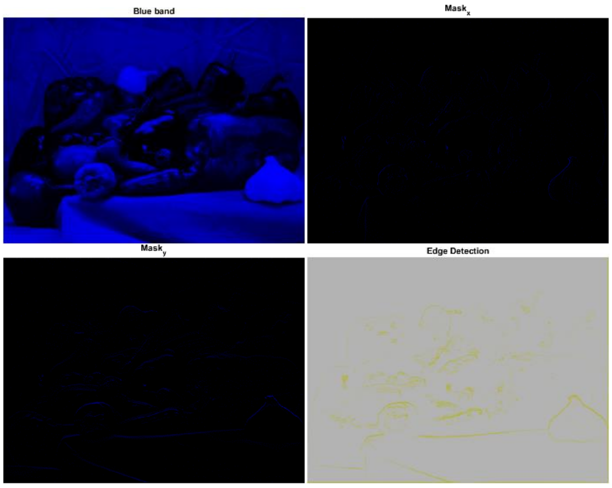


Fig. 9: Appy fuzzy logic on the blue band

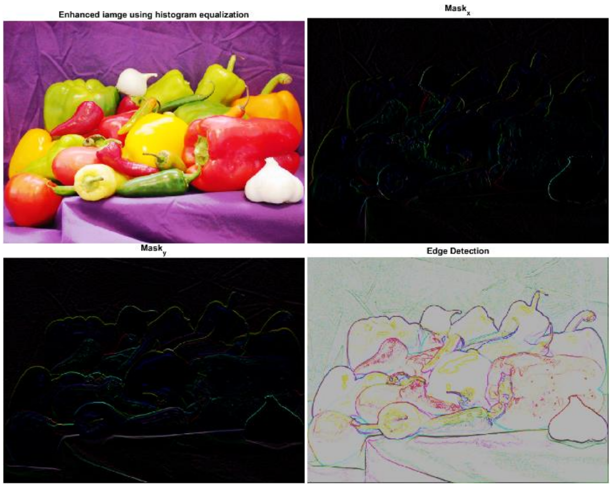
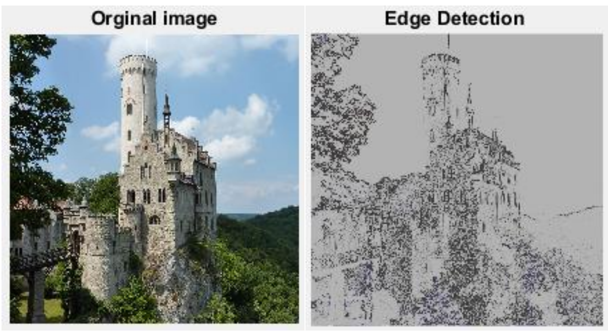


Fig. 10: Result of soft computing edge detection on color image

Consequently, to test our proposed method, we used a different color image (City, Jelly_cc11, Baboon, Lena, and Peppers). Fig 11 depicts the detected edge on the sample color image. The detected edges were detailed to the general shape of the image and did not contain additional elements. Most importantly, they describe the external appearance only of the color image.



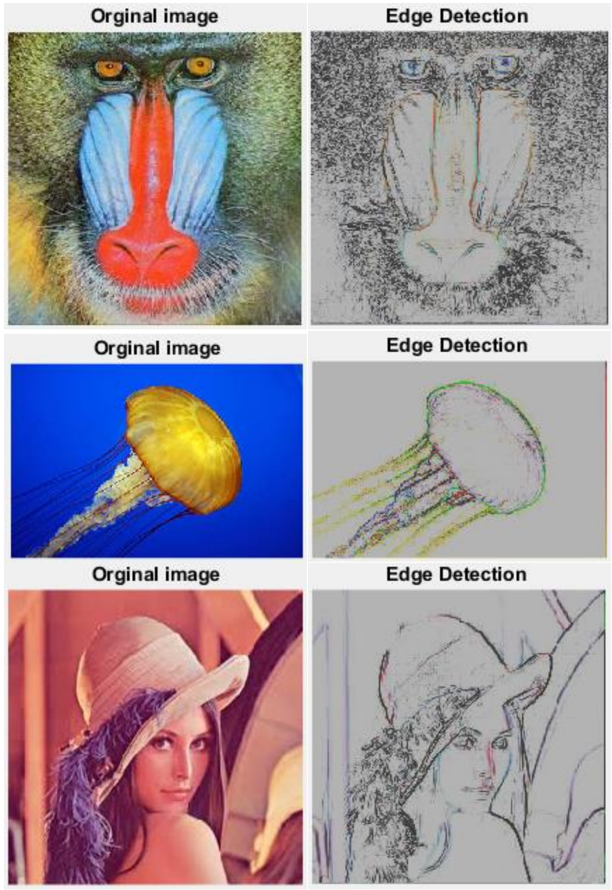


Fig. 11: Result of soft computing edge detection on sample color image

Moreover, our proposed method can detect both colored and binary edges. A visual comparison of the proposed method with various methods on the Baboon image is established in Fig. 12.

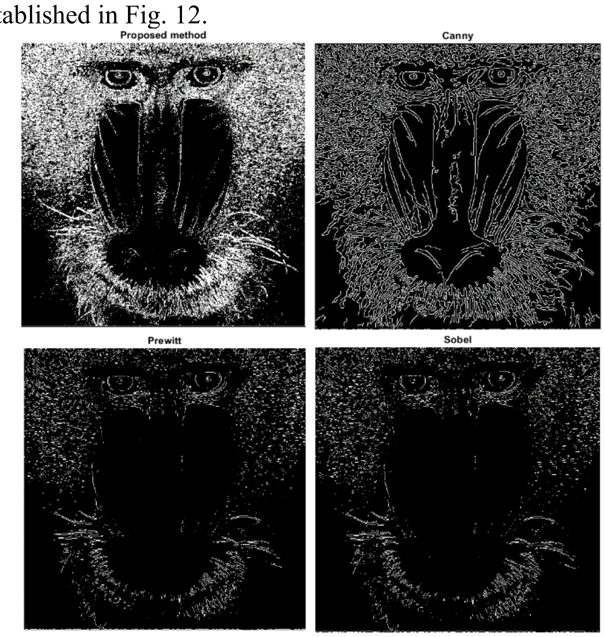


Fig. 12: visual comparison of the proposed method with various methods.

We prove that our output is better than other outputs by using metrics like PSNR (Peak Signal Noise Ratio) and MSE (Mean Square Error). The PSNR and MSE are the most frequently used parameters or metrics to determine the image quality. MSE is inversely proportional to PSNR. Lesser the

MSE more will be the quality of the image. Additionally, the PSNR will be the quality of the image. Our objectives include 1—accurate detection of the edges or boundaries, 2. Performance should not vary much from image to image, 3. Complexity should not be increased, 4: error-free edge detection, 5. The efficiency of the system should increase. This study is to work on human face images so that the differences easily from image to image. This experimental setup will focus on accurately detecting the edges or boundaries. Performance should not vary much from image to image. Complexity should not be increased; error-free edge detection and system efficiency should increase, as shown in TABLE II and TABLE III.

TABLE II
PSNR OF DIFFERENT TYPES OF EDGE DETECTION

Image	Proposed	Canny	Sobel	Prewitt
city	9.6340	5.0285	5.0211	4.6478
Jelly_cc11	6.8520	5.7660	5.7729	5.7488
Baboon	12.0877	5.3168	5.3178	5.2312
Lena	10.8028	5.1046	5.1062	5.0404

TABLE III
MSR OF DIFFERENT TYPES OF EDGE DETECTION

Image	Proposed	Canny	Sobel	Prewitt
city	0.1088	0.3142	0.3147	0.3429
Jelly_cc11	0.2064	0.2651	0.2647	0.2661
Baboon	0.0618	0.2940	0.2939	0.2998
Lena	0.0831	0.3087	0.3086	0.3133

V. CONCLUSIONS

In this paper, a new approach to fuzzy logic-based edge detection has been demonstrated. First, two masks are used to gather data on edge strength for this method. Then, GMF is used to fuzzify the mask input. After that, sixteen FIS rules are suggested in the proposed method, and fuzzy if-then rules are used to classify the membership into black, white, or edge groups. Finally, the final edge image is produced using the MFI. Furthermore, the simulation results show a clear difference between the proposed method and the current state of the art regarding computational costs and color image edge quality. However, the proposed method can determine the boundaries of particular-colored regions for further color image analysis in various digital image processing applications such as face recognition, remote sensing, medical imaging, and other areas.

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