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Fuzzy Inference System Based Edge Detection and Image Sharpening Technique

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Abstract- This work proposes a novel technique for enhancement of digital images, specifically sharpening of satellite images. A technique called unsharp masking is modified for this task. In unsharp masking, high frequency data is emphasized in a image. In this paper, the authors have modified the method to extract the high frequency data from the image; Fuzzy logic based system is used for this task. As soon as the high frequency data is available, it can be embossed over the image to sharpen the edges. A comparative analysis is also provided with conventional operator based edge detection techniques. The proposed algorithm provides better results.

Index Terms- Edge Detection, Image Sharpening, Fuzzy Logic

1. INTRODUCTION

Modern time is an era of technology in which we now believe in the vision based intelligence. Penetration of computers into each area of the market and living has forced the designers to add the capability to see and analyse and to innovate more and more into the area of electronic vision or image processing. At the level of computational intelligence for electronic vision, many of the algorithms have been developed to extract different types of features from the image such as edges, segments and lot many other types of image features.

In order to perceive images correctly, visual enhancement specifically sharpening of digital images is important. Various researchers have proposed different algorithms for sharpening of edges in a digital image.

Huang et. al. [1] proposed an algorithm based on wavelet transform, Teager energy operator, and human visual properties to improve the unsharp-masking technique for image sharpening. Ying et. al. [2] proposed another algorithm based on wavelet transform for image sharpening. First, an image containing the edge information of the original image was obtained from a selected set of wavelet coefficients. This image was then combined with the original image to generate a new image with enhanced visual quality. In addition, an effective approach was designed to remove those coefficients related with noise rather than the real image to further enhance the image quality.

Bouledjfane et. al. [3] proposed a new technique for image sharpening based on Unsharp Masking (UM), and Bidimensional Empirical Mode Decomposition (BEMD). Firstly, the image was decomposed into a set of bidimensional intrinsic mode functions (BIMFs) and the residual image. Afterward, a weighting mask was achieved from an edge map multiplied by a compensation factor. Then, weighting mask was applied to the first mode. Finally, the reconstruction of the sharpened image was done by summing the compensated BIMF1 with the rest of the other modes and the residual image.

Negi et. al. [4] proposed an approach that simultaneously adjusts contrast and enhances boundaries. Histogram has been plotted to verify the result of various cases arising due to implementation of contrast stretching on image sharpening. Edge enhancement is done for MRI knee images.

Alsam et. al. [5] presented a fast algorithm that spreads the high frequencies of an image to successively lower resolutions resulting in an improvement in sharpness and local contrast. The algorithm is similar to the well established unsharp masking with certain fundamental differences. The image is blurred with a Gaussian filter and a difference image representing the high frequencies is calculated. This difference is then amplified and added back to the blurred image and the process is repeated without altering the original high frequencies.

Environmental remote sensing is the measurement, from a distance, of the spectral features of the Earth's surface and atmosphere by sensor at the satellites or aircraft. These measurements are formed by the digital image of surface using satellites. For any particular area that is being imaged it is likely that the image will be a bit blurred and not visible with clarity. Thus, enhancement of satellite images is important. Many researchers have proposed different algorithms for enhancement of satellite images.

Vorobel et. al. [6] proposed a technique to improve the contrast between the dark and light areas for small detail in satellite images. Singhai et. al. [7] proposed a technique for enhancing various slow motion underwater, ground, and satellite images, taken from underwater submarines and celestial sites. A novel extension of histogram equalization, actually histogram specification, named brightness preserving histogram equalization with maximum entropy (BPHEME).

Attachoo et. al. [8] developed a unique method of image filtering that enhances the detail and sharpens the edges of colored satellite images. Histogram equalization coupled with a two stage data filtering process that applies convolution with Laplacian and sharpening with Laplacian through the 3 color bands that produce the colored satellite images has yielded sharper clearer images.

Taşmaz et. al. [9] proposed a satellite image enhancement system consisting of image denoising and illumination enhancement technique based on dual tree complex wavelet transform (DT-CWT). The technique firstly decomposes the noisy input image into different frequency subbands by using DT-CWT and denoises these subbands by using local adaptive bivariate shrinkage function (LA-BSF) which assumes the dependency of subband detail coefficients.

Nuaimi et. al. [10] deals with the design and analysis of 2D filters for improving the resolution of interpolated satellite images. The images are reduced first by a certain factor and then interpolated back to the original size. Linear phase 2D filters are designed to optimize the structural similarity index measure (SSIM). Then the satellite image is enlarged by the same factor and the 2D filter is used to sharpen the image.

Thriveni et. al. [11] proposed a DWT-PCA based fusion and Morphological gradient for enhancement of Satellite images. The input image is decomposed into different sub bands through DWT. PCA based fusion is apply on the low-low sub band, and input image for contrast enhancement. IDWT is used to reconstructs the enhanced image. To achieve a sharper boundary discontinuities of image, an intermediate stage estimating the fine detail sub bands is required. This is done by the success of threshold decomposition, morphological gradient based operators are used to detect the locations of the edges and sharpen the detected edges.

Edge detection is also an important concern. Many authors have proposed various techniques for edge detection. [16]. Initially, a lot of work was done to present linear and non-linear operators. In recent years, many researchers have supported objectives of optimization of edge detection. Traditional methods such as Roberts [12], Sobel [13] and Prewitt [14] do not carry out edge correction optimally and also are very sensitive to noise. Canny [15] technique improved edge detection but still it suffered from some drawbacks. Thus, new methods have been developed by researchers all over the world.

One of the early work in the field of edge detection in digital images include Rosenfeld's work on non linear operator [17]. In his work, major edges in a picture were detected by subtracting averages taken over pairs of adjacent non-overlapping neighborhoods, but this method does not locate the edges precisely. He found that using a product of such differences of averages tends to yield sharply localized edges.

Griffith [18] proposed a system of programs for the detection of the straight edge lines in simple scenes. Distinct lines were detected by a procedure which was relatively inexpensive. Then, the more subtle lines are located by a search that is much more costly per unit area, but which is only applied to certain areas suggested by the locations of the lines already found.

Sun et. al. [19] proposed a nonlinear point operator, followed by a usual edge detector, e.g. the Sobel edge detector. Three point operator functions were defined and their effects on edge detection were analysed.

Stanger [20] presented a new technique for combining restored images which have different characteristics. Images were combined at the pixel level by performing a weighted average operation where the weights are derived from local image gradients estimated by the Sobel edge detector.

Gradient edge operators such as the Sobel, Prewitt and Roberts operators all required a square root operation which is computationally intensive. Mitchell [21] proposed a new square root algorithm specifically designed for use with these edge operators.

Gongyuan et. al. [22] proposed a modified morphological gradient which can overcome the drawbacks of the basic gradient approach for edge detection; provision of only a magnitude response without edge orientation, magnitude response which is dependent on the orientation of the object edge and more sensitivity to added noise than well known linear gradient estimators.

Da-Shun et. al. [23] presented a method of edge parameters extraction based on the vertical template in the Sobel operator combining the inter-frames correlation of the target and background in image series. This method decreased the superfluous pixels of background and increase the processing speed of edge detection.

Boonchieng et. al. [24] proposed an edge detection and segmentation method for two-dimensional echocardiogram to present the procedures to detect and segment an image from two-dimensional echocardiogram and to generate a scanline that can be used to detect the distance between two endocardiums which is useful to analyze heart disease.

Liang et. al. [25] presented a new edge detection method. The main contribution was the application of empirical mode decomposition (EMD) to detect the image edge. The EMD algorithm can decompose any nonlinear and non-stationary data.

Zhongshui et. al. [26] proposed color image edge detection method based on conversion transformation between RGB color space and YUV color space and histogram equalization transformation.

Zhang et. al. [27] presented a key technique based on image edge detection algorithm which adopts the Canny operator to accomplish the job of edge detection and foreground object extraction from the perspective of image processing, also has been compared with other detection methods. Chaple et. al. [28] presented a paper for real-time image processing applications on reconfigurable device like FPGAs.

Recently, Yuan et. al. [29] presented an adaptive image edge detection algorithm based on Canny operator. Method combines global with local edge detection to extract edge. The global edge detection can obtain the whole edge, which uses adaptive smooth filter algorithm based on Canny operator.

This paper proposes a modification of unsharp masking technique for sharpening of satellite images based on fuzzy inference system for edge detection [30]. The edge detection using Fuzzy logic system is discussed in section II with an example. Section III discusses the conventional unsharp masking algorithm. Section IV discusses the simulation setup and sharpening results for a satellite image. Section V concludes this paper.

2. EDGE DETECTION USING FUZZY LOGIC

Edge is defined as object border, and extracted by features such as graycolor or texture discontinuities. Luminance and geometrical features, lightening condition and noise volume has a great impact on shaping the edge. Edge contains important information of image and provides object's location. Edge is considered an important feature in a digital image and is used for image enhancement, restoration and segmentation.

2.1. Basics of Edge Detection

Edge detection is a fundamental tool in image processing and computer vision, particularly in the areas of feature detection and feature extraction, which aim at identifying points in a digital image at which the image brightness changes sharply or more formally has discontinuities. The contrast is improved by increasing the difference across discontinuities of the image components. In order to improve the differences, they have to be detected. The edge detection algorithm is designed to detect and highlight these discontinuities. Discontinuities in image brightness are likely to correspond to discontinuities in depth, discontinuities in surface orientation, changes in material properties or variations in scene illumination. The purpose of detecting sharp changes in image brightness is to capture important events and changes.

The goal of edge detection is to locate the pixels in the image that correspond to the edges of the objects seen in the image. This is usually done with a first and/or second derivative measurement following by a comparison with threshold which marks the pixel as either belonging to an edge or not. In the ideal case, the result of applying an edge detector to an image may lead to a set of connected curves that indicate the boundaries of objects, the boundaries of surface markings as well as curves that correspond to discontinuities in surface orientation. Thus, applying an edge detection algorithm to an image may significantly reduce the amount of data to be processed and may therefore filter out information that may be regarded as less relevant, while preserving the important structural properties of an image.

2.2. Edge detection algorithms

Various edge detection algorithms have been developed in the process of finding the perfect edge detector. Most of conventional operator based techniques may be grouped into two types:

(1) Gradient (difference) based operators: In the gradient based edge detection we find an estimate of the gradient magnitude using the smoothing filter and use the found estimate to determine the position of the edges. It means that the gradient method detects the edges by looking for the maximum and the minimum in the first derivative of the image. Magnitude of the gradient of image is given by

$$\left|grad\ f(x,y)\right| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2} \quad (1)$$

It is based on the investigation of the image function's behaviour in a small neighbourhood. The practical implementation is done via convolution masks. The operators approximating first derivatives have to contain separate masks for each direction. But in vast majority of cases, only the differences in the vertical and horizontal directions are calculated which means that only two convolution masks are used. These operators are, for example, Canny Operator, Roberts operator, Prewitt operator, Sobel operator etc. All the kernels are mostly normalized.

(2) Laplacian (zero-crossing) based operators: In the Laplacian method we find the second derivative of the signal and the derivative magnitude is maximum when second derivative is zero. In short, Laplacian method searches for zero crossings in the second derivative of the image to find edges. The original image can be easily restored from its edges.

$$\left|lap\ f(x,y)\right| = \nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \quad (2)$$

The Laplacian operator has the ability to detect the edges by convolution with a single mask. It comes from the fact that if the edge is the extreme of first derivative, the second derivative should be zero.

(3) Operators based on Parametric edge: These try to estimate continuous image function from the discrete image. This is, of course, very complicated and computationally demanding. Nevertheless, their results seem to be more reliable than the results of classical convolution mask methods and could work on the sub-pixel level.

2.3. Characteristics of an edge detector

Several algorithms exist for edge detection. A good edge detection algorithm should possess following characteristics:

(1) To identify less number of false edges and detection of real edges should be maximum.

(2) The marked pixels should be closer to the true edge.

(3) Error of detecting more than one response to single edge (double edges) should be less.

(4) To design one edge detector that performs well in several contexts (Satellite images, face recognition, medical images, natural images etc.)

2.4. Fuzzy Logic Based Edge Detection

Fuzzy logic is a perfect problem-solving methodology with a myriad of applications in embedded control and information processing. Fuzzy provides a remarkably simple way to draw definite conclusions from vague, ambiguous or imprecise information. It means that fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions. Fuzzy logic and probability theory are the most powerful tools to overcome the imperfection. Fuzzy logic is a version of first- order logic which allows the truth of a statement to be represented as a value between 0 and 1, rather than simply True (1) or False (0). To perform image processing using fuzzy logic, three stages must occur. First, image fuzzification is used to modify the membership values of a specific data set or image. After the image data are transformed from gray-level plane to the membership plane using fuzzification, appropriate fuzzy techniques modify the membership values. This can be a fuzzy clustering, a fuzzy rule-based approach, or a fuzzy integration approach. Decoding of the results, called defuzzification, then results in an output image. "The main power of fuzzy image processing is in the modification of the fuzzy membership values."

The image shown in Fig. 1. will be used for explaining the edge detection algorithm using fuzzy logic.

(1) Image fuzzification

The image that read is gray scale image and data might range from 0 to 255. The data 0 belongs to black pixel of the image and data 255 belongs to while pixel of the image. In order to apply the fuzzy algorithm, data should be in the range of 0 to 1 only. The image data are converted to this range that is known as membership plane, after the image data are transformed from gray-level plane to the membership plane (fuzzification); appropriate fuzzy techniques modify the membership values. This can be a fuzzy clustering, a fuzzy rule-based approach and a fuzzy integration approach.

Fig. 1 Image used for edge detection using fuzzy logic

Next image gradient is computed is shown in Fig.2. The gradient is computed both in horizontal (X) direction and in vertical (Y) direction.

(2) Fuzzy Inference system

The system implementation was carried out considering that the input image and the output image obtained after defuzzification are both 8-bit quantized; this way, their gray levels are always between 0 and 255. The fuzzy sets were created to represent each variable's intensities; these sets were associated to the linguistic variables "Black" as background and "White" as Edge. After computing the gradient of the image, the higher value represent edge and lower values, the background. The adopted membership functions for the fuzzy sets associated to the input and to the output are as shown in Fig. 3 and 4.

The functions adopted to implement the "and" and "or" operations were the minimum and maximum functions respectively. The Mamdani method was chosen as the defuzzification procedure, which means that the fuzzy sets obtained by applying each inference rule to the input data were joined through the add function; the output of the system was then computed as the low of the resulting membership function. The values of the three membership's function of the output are designed to separate the values of the blacks and whites and edges of the image. In many image processing applications, expert knowledge is often used to work out the problems. Expert knowledge, in the form of fuzzy if-then rules, is used to deal with imprecise data in fuzzy set theory and fuzzy logic.

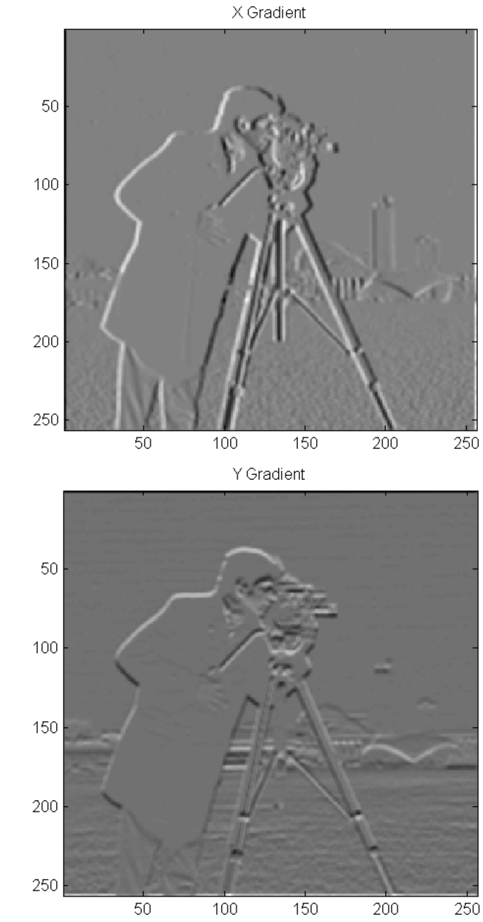


Fig. 2 Image gradients

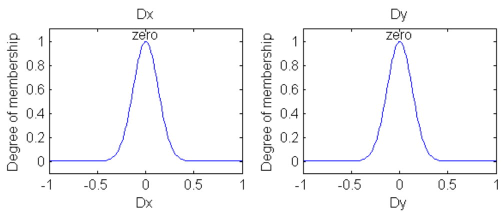


Fig. 3 Input Membership functions

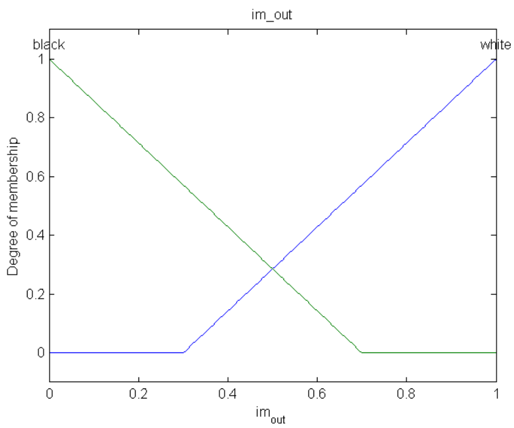


Fig. 4 Output Membership functions

(3) Fuzzy inference rule

The Inference rule depends on value of the gray level pixels of the fuzzified data set; in this case fuzzified gradient images. Two rules are used based on and-or conditions. In bothe gradients are low, the pixel is background. If any of the pixel is high, data is edge data. The powerful feature of these rules is the ability of extract all edges in the processed image directly.

(4) Defuzzification

From the side of the fuzzy construction, the input grays is ranged from 0-255 gray intensity, and according to the desired rules the gray level is converted to the values of the membership functions . The Mamdani method was chosen as the defuzzification procedure, the output of the FIS according to the defuzzification is presented in Fig. 5.

Fig. 5 Edge detected Image

3. UNSHARP MASKING

Image sharpening using unsharp mask is by far the most popular technique. It has its roots in analog photography where the blurred version of the photo used to be printed together with the negative in the form of registered sandwich. This would increase edge sharpness as well as suppress the noise caused by the film grain which is random for both versions. The name of the procedure comes from the fact that the unsharp version is used as a mask. But the massive popularity of unsharp mask came with the digital photography.

The principle of it is to extract the high frequency components by subtracting the blurred version from the original ($\boldsymbol{X}$). This may also be achieved by directly computing the high frequency components using edge detection process. Let us denote it by $\boldsymbol{X}_{\boldsymbol{high}}$. Once the high frequency components are available, the sharpened image can be computed.

$$X_{sharp} = X + a\, X_{high} \qquad (2)$$

Steps involved in unsharp masking:

Step 1: Extract the high frequency components. Two primary methods are available for this:

a. Subtracting the blurred version of the image (low frequency components) from the original image.

b. Using high pass filter/edge detectors

Step 2: Adding the extracted high frequency components to original image.

The authors have proposed a modified version of the Unsharp masking process by changing the method to extract the high frequency components. Instead of subtracting the blurred version of the image (low frequency components) from the original image or using conventional high pass filter/edge detectors, we are extracting the high frequency components using Fuzzy Inference System.

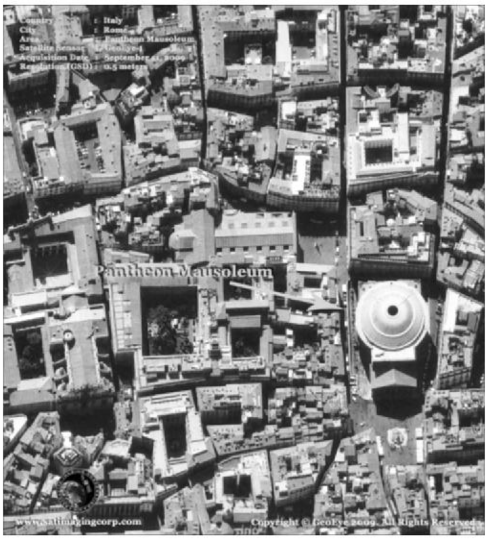


Fig. 6 Satellite Image

4. SIMULATION AND RESULTS

The satellite image used the illustration of sharpening algorithm is shown in Fig. 6.

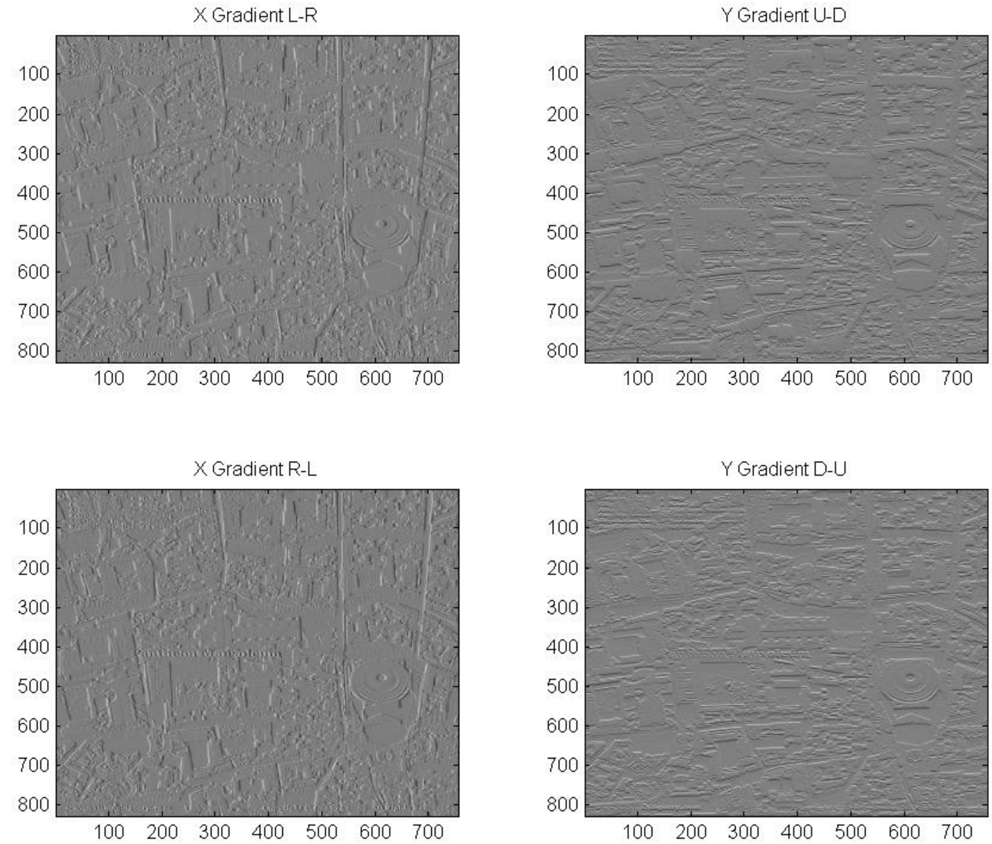
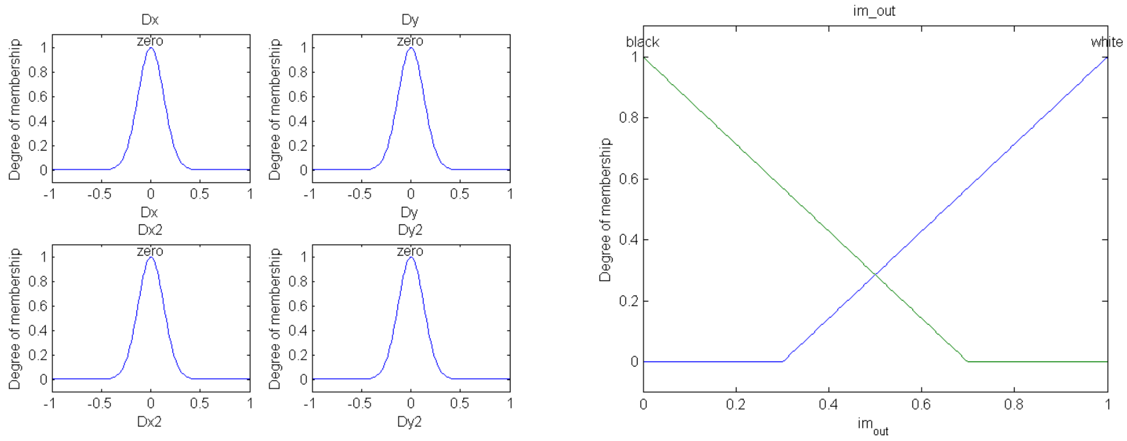


Fig. 7 Gradient Images



(a) (b)

Fig. 8 Membership functions (a) for Inputs (b) for Outputs

It is normalized (divide by 255, so range from 0 to 1) and then 4 gradient images are computed (2 in each direction) as shown in Fig. 7. Next, a fuzzy inference system is designed whereby inputs are defined as gradient images. Membership function have to be defined for input and output as shown in Fig. 8. Also fuzzy inference rules are created. Let Dx and Dx2 be the gradient images in horizontal direction while Dy and Dy2 be the gradient images in vertical direction. im_out be the output image. The inference rules used are:

1. If (Dx is zero) and (Dy is zero) and (Dx2 is zero) and (Dy2 is zero) then (im_out is black)
2. If (Dx is not zero) or (Dy is not zero) or (Dx2 is not zero) or (Dy2 is not zero) then (im_out is white)

The result of edge detection is shown in Fig. 9. Also, the results are compared with other edge detection techniques as shown in Fig. 10. The detected edges are embossed onto the original image and the results of sharpening are shown in Fig. 11. Finally, the results are compared with the conventional algorithms in Fig. 12.

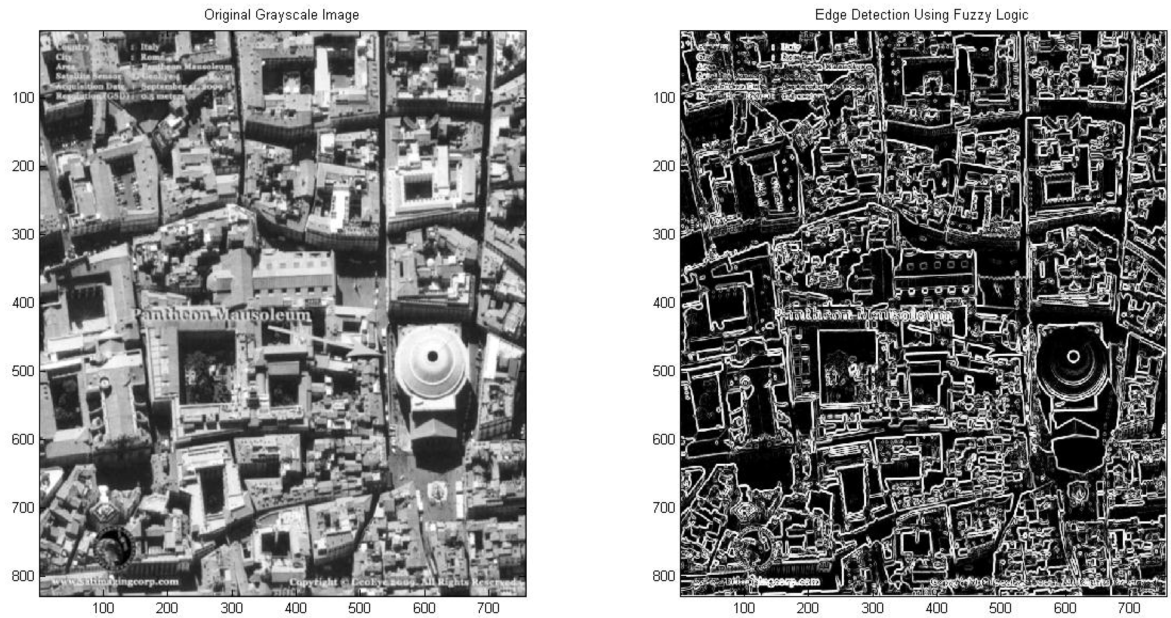


Fig. 9 Result of edge detection

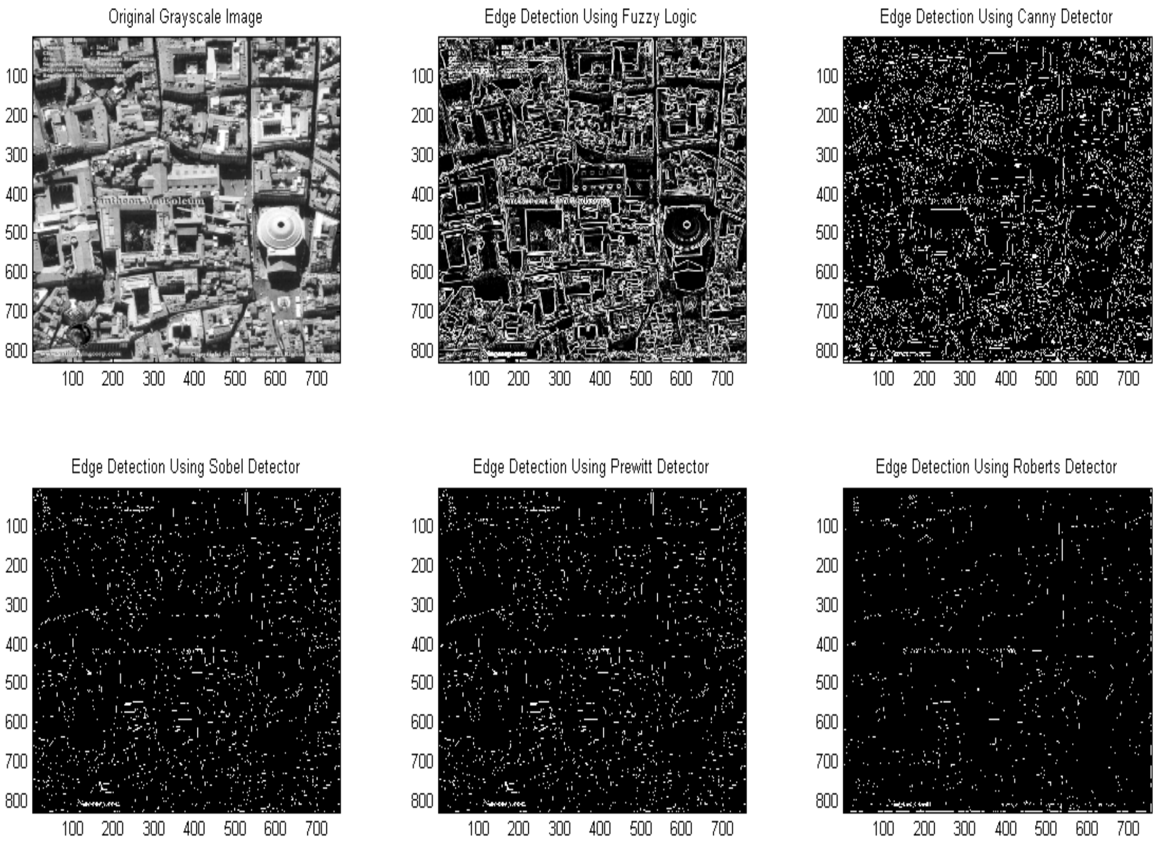


Fig. 10 Comparison of edge detection techniques

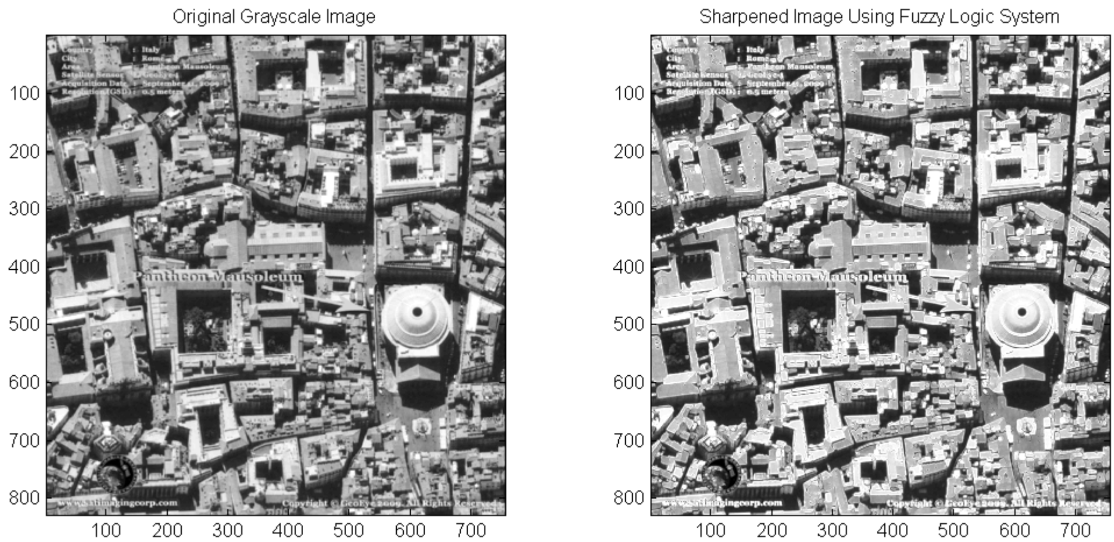


Fig. 11 Result of sharpening

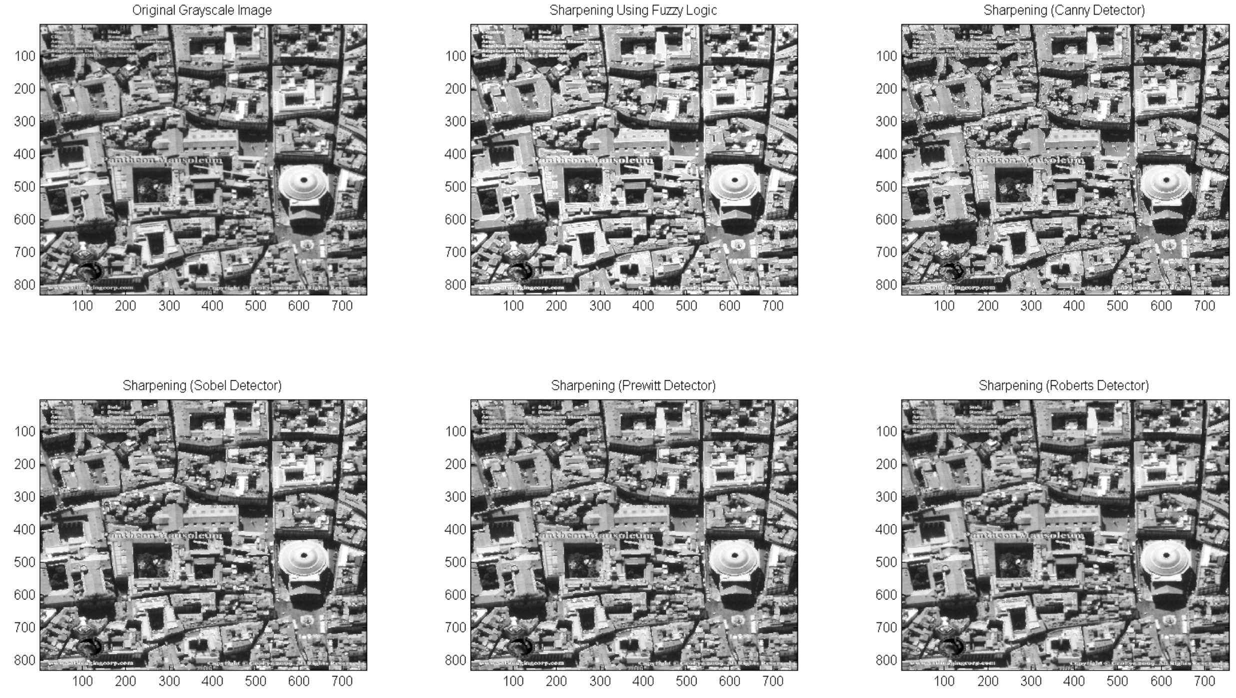


Fig. 12 Comparison of sharpening techniques

5. CONCLUSION

In this paper, a new technique for sharpening of satellite images is presented. First, various concepts related to edge detection in digital images are studied. Then, a comprehensive discussion of fuzzy based edge detection and unsharp masking is provided. Finally, a comparative analysis of proposed technique with other techniques is provided. From various results shown in Fig. 12 and 13, it can be concluded that the proposed technique provides sharpening results far better than the other techniques compared.

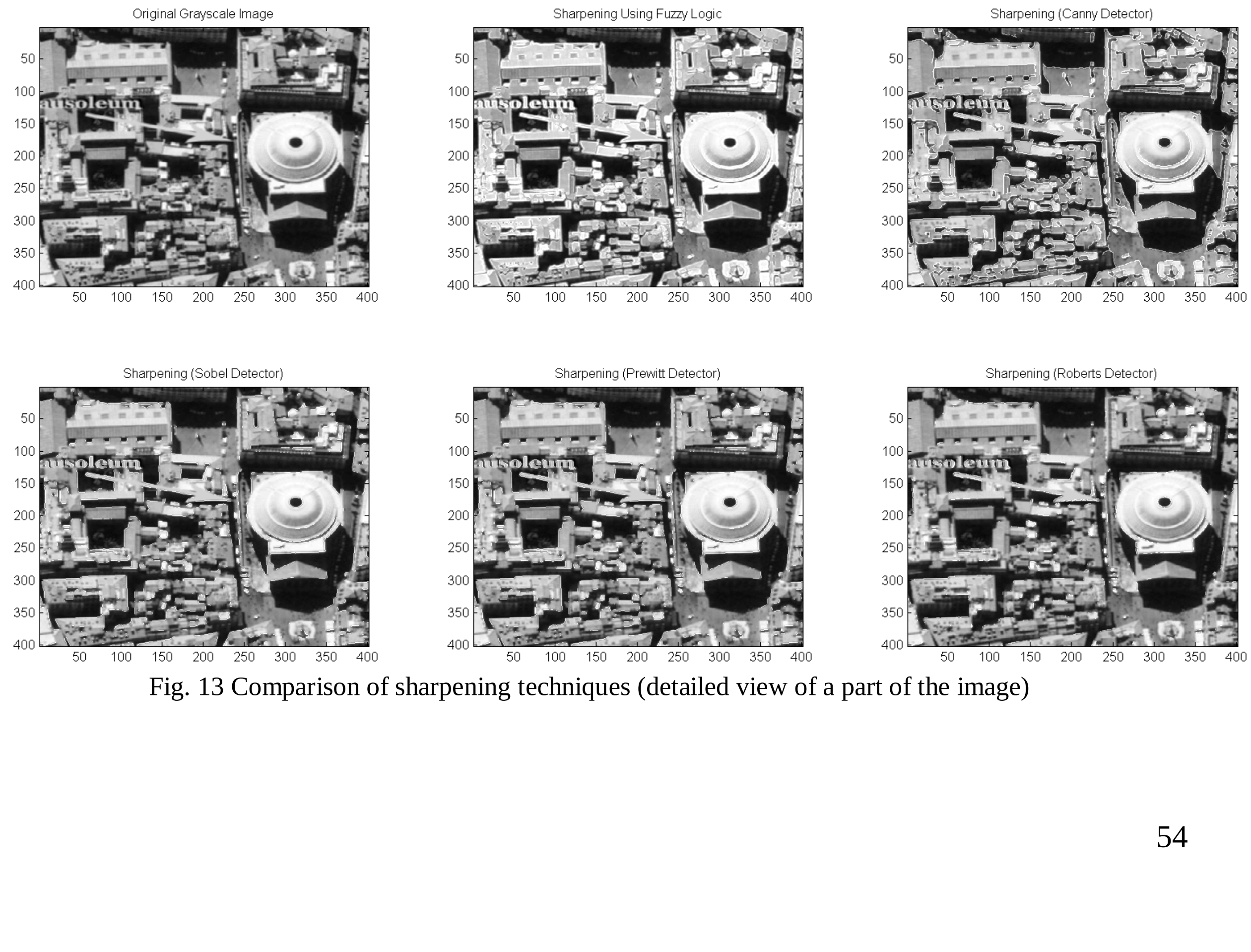


Fig. 13 Comparison of sharpening techniques (detailed view of a part of the image)

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