Quality Improvement of Liver Ultrasound Images Using Fuzzy Techniques

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doi: 10.5455/aim.2016.24.380-384
ACTA INFORM MED. 2016 DEC; 24(6): 380-384
Received: SEP 15, 2016 • Accepted: NOV 22, 2016

ABSTRACT

Background: Liver ultrasound images are so common and are applied so often to diagnose diffuse liver diseases like fatty liver. However, the low quality of such images makes it difficult to analyze them and diagnose diseases. The purpose of this study, therefore, is to improve the contrast and quality of liver ultrasound images. **Methods:** In this study, a number of image contrast enhancement algorithms which are based on fuzzy logic were applied to liver ultrasound images - in which the view of kidney is observable - using Matlab2013b to improve the image contrast and quality which has a fuzzy definition; just like image contrast improvement algorithms using a fuzzy intensification operator, contrast improvement algorithms applying fuzzy image histogram hyperbolization, and contrast improvement algorithms by fuzzy IF-THEN rules. **Results:** With the measurement of Mean Squared Error and Peak Signal to Noise Ratio obtained from different images, fuzzy methods provided better results, and their implementation - compared with histogram equalization method - led both to the improvement of contrast and visual quality of images and to the improvement of liver segmentation algorithms results in images. **Conclusion:** Comparison of the four algorithms revealed the power of fuzzy logic in improving image contrast compared with traditional image processing algorithms. Moreover, contrast improvement algorithm based on a fuzzy intensification operator was selected as the strongest algorithm considering the measured indicators. This method can also be used in future studies on other ultrasound images for quality improvement and other image processing and analysis applications.

Keywords: ultrasound image, fuzzy logic, image processing.

1. INTRODUCTION

Ultrasonography is a common, non-invasive and relatively cheap and available diagnostic tool (1-3). Ultrasound liver imaging is known as one of the common methods for the early detection of diffuse liver diseases, such as fatty liver (3-5). To diagnose fatty liver disease in liver ultrasonography, the liver contrast is compared with that of adjacent organs such as kidney. Although this method is effective, it is prone to human errors because of the low quality of sonography images (5, 6). Another feature is tissue unclearness in images, which can lead to disagreement in border areas of an image and can be very confusing. In addition, the similarity of diagnostic areas is so strong in certain conditions that can confuse sonographers even more (7).

Improving the quality and resolution of ultrasound images is an important issue in the processing and analysis of such images to enhance diagnostic accuracy. The main goal of image preprocessing is improvement of image quality; that is, the resulting images hould be more appropriate for a particular application than the primary image; therefore, quality improvement methods depend on the type of problem (8). Improving the quality of images includes various operations such as contrast improvement, modification of the image's gray levels based on the histogram, and the like. Contrast enhancement and brightness of images is considered as one of the preparatory steps to analyze medical images (9, 10). The aim of contrast enhancement is to convert dark pixels to darker values, and pixels with high gray levels to brighter values. In fact, creating an image with a higher contrast than that of the initial image is done through assigning more weights to pixels with values closer to the mean of gray levels. In recent years, the theory of fuzzy sets has been successfully applied in machine vision and image processing. The fuzzy logic is a powerful tool when facing with uncertainties related to the ambiguity in the interpretation of images with low levels of brightness and the detection of edges, borders, features, and the like. Image contrast is also a feature based on human perception, and its approximate definition is as follows:

Formula 1:

C=(A-B)/(A+B)

Where A and B are mean gray levels of the two areas the contrast of which is calculated. By increasing the contrast among different parts, the final image will be improved (9, 11). Therefore, since the definition of image contrast is in a way a fuzzy definition, it will be reasonable to use fuzzy logic for contrast enhancement (12). The method applied in this study is image quality enhancement using fuzzy techniques, and will be compared with histogram equalization method - which is a common method in image processing - based on the least mean squared error and signal to-noise ratio of the image. Mapping the images into a fuzzy area will improve image edge detection and image understanding parameters. Meanwhile, other pre-processing algorithms, including feature extraction or extraction of apart of the liver, will be better conducted (4). Therefore, after the intended algorithms are implemented, thresholding power to extract the liver surface will also be studied on different images to find out the performance power of algorithms.

2. MATERIALS AND METHODS

This study consisted of two steps. In the first phase, four algorithms of contrast enhancement were implemented in Matlab 2013b software to improve the quality of liver ultrasound images. 85 B-mode ultrasound images obtained from ultrasonography ward of Tehran Gastroenterology and Hepatology Center (TGHC) the Masoud consultation clinic of digestive and liver diseases during the second/latter half of the Iranian year 1393 (2014-5) including the three grades of normal, moderate and severe and then stored in a BMP format. Second, the strengths of algorithms were compared to assess these methods.

In recent years, many researchers have used fuzzy techniques in image processing (9, 12), some of which include fuzzy methods of contrast enhancement using a fuzzy intensification operator, image contrast enhancement by fuzzy histogram hyperbolization, contrast enhancement by fuzzy

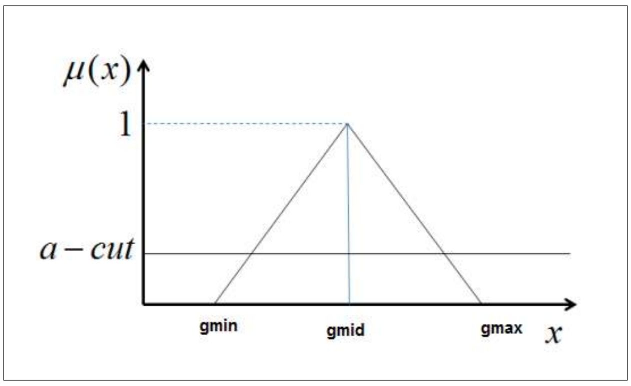

Figure 1. Triangular membership function for mapping of gray levels and modify in gresolution of the image; g is the value of gray surfaces of the input image

IF-THEN rules, and histogram equalization; these methods are applied in this study to improve image contrast. To survey fuzzy techniques, the function μ (x) is used to understand the degree of brightness or darkness of image pixels in the fuzzy contrast enhancement. In first step of this study for image enhancement, the membership functions are defined as Figure 1, where the grey values of pixels are the input (12).

In this study, membership functions are considered as triangles (12). Then, a transfer is performed on them to develop in the image a new membership function of the number of pixels. Finally, an inverse transform is carried out on the new membership function to turn the membership values of pixels to the original state.

The overall method in the fuzzy improvement of images is as follows in Figure 1:

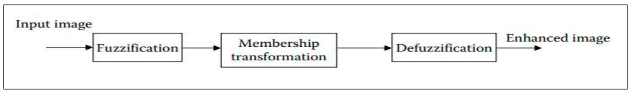

Figure 2. Steps of fuzzy quality improvement of images

The fuzzy methods used in this study areas follows:

a) Contrast enhancement using a fuzzy intensification operator. In this method, an intensification operator is used to increase the image contrast. For an image, if the gray level in position (m, n) is shown by g_{mn}, and the maximum and minimum gray levels byg_{max} and g_{min}, respectively, the membership function will be defined as follows (11):

Formula 2:

$$\mu_{mn} = \left[1 + \frac{g_{max} - g_{mn}}{F_d}\right]^{-1}$$

where the amount ofis the range of gray levels, which isabout 255 in gray ultrasound images. To achieve an optimal value in the image, the membership values greater than 0.5 are then mapped to larger values and the values less than 0.5 to lower values by an intensification operator. The INT operator was considered in this study as follows (8, 10):

Formula 3:

$$\mu'(g) = \begin{cases} 2[\mu(g)]^2 & 0 \le \mu(g) \ge 0.5 \\ 1 - 2[1 - \mu(g)]^2 & 0.5 < \mu(g) \ge 1 \end{cases}$$

b) Image contrast enhancement by fuzzy histogram hyperbolization. Perception of brightness is a nonlinear practice by humans. Therefore, the method modifies the image histogram in a logarithmic way. The fuzzy expansion phase of this formula is as follows (11):

Formula 4:

$$g' = \left(\frac{(L-1)\left(e^{-\mu(g)^{\beta}} - 1\right)}{e^{-1} - 1}\right)$$

In this formula, if the value of β gets close to zero, the image will be too bright and if it moves towards infinity, the image will be too dark. The new values of the image are calculated by this function and based on Figure 2.

c) Image contrast enhancement by fuzzy IF-THEN rules

The fuzzy approach based on IF-THEN rules is a powerful and comprehensive method for many applications in image processing. A simple inference system to extract rules in medical applications is defined as:

The bright pixels are mapped into brighter values, dark pixels into darker values, and gray pixels to gray values, showed in Figure 3 (11, 13).

In the second step, the evaluation of images has been done based on three methods: observer sensitivity which is the visual comparison of the output images, quality measurement done by common quality measurement methods such as peak signal-to-noise ratio (PSNR) and mean squared error (MSE), and testing the power of an image segmentation algorithm after the implementation of the intended algorithms (13, 14). The existence of edges is necessary to distinguish the liver from its surroundings. To measure the power of segmentation algorithm, the ot us image thresholding technique for liver extraction was used so that the strength of the intended algorithms in separating the liver surface could be measured.

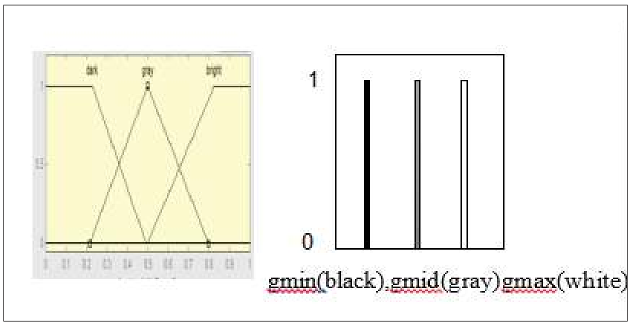

Figure 3. Rule-based improvement contrast:
Left: Input membership function to fuzzify the gray surface simple mented in MATLAB

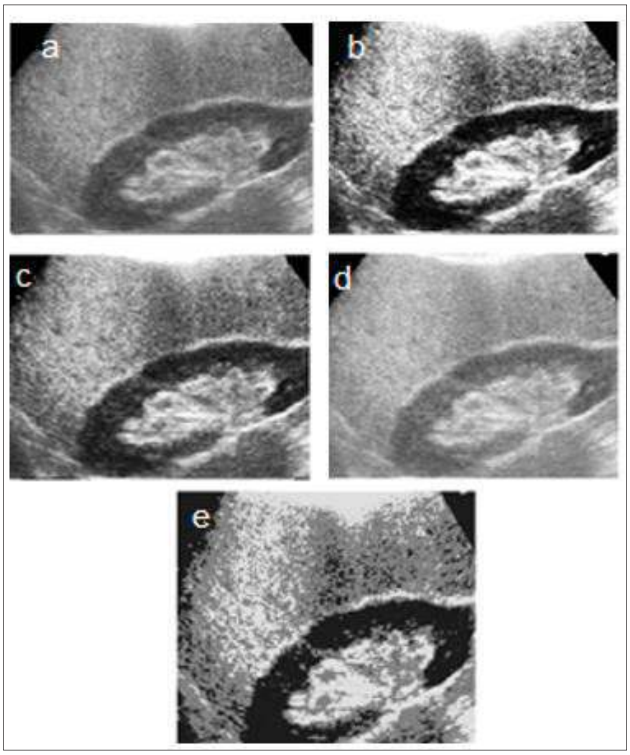

Figure 4. Visual comparison of images with the implementation of algorithms. From left to right: a: original image, b: image after histogram equalization, c: image after a fuzzy intensification operator, d: fuzzy histogram hyperbolization β=1, e: after fuzzy IF–THEN rules

3. RESULTS

In this study, three fuzzy techniques for image processing, and a common quality improvement technique of image processing were compared with each other in the liver ultrasound images.

According to the Figure 4, images were visually improved after the implementation of algorithms inseparability of edges, details of images, and also resolution and contrast. MSE and PSNR values of the measured images are shown in Table 1.

Type of algorithm	PSNR	MSE
Histogram equalization method	64.5050	0.0230
Fuzzy intensification operator improvement method	70.1981	0.0062
Fuzzy hyperbolization improvement method	67.2775	0.0122
Enhancement method based on IF–THEN rules	64.9679	0.0207

Table 1. Comparison of four algorithms implemented on images based on the MSE and PSNR

As it can be seen in Table 1, the mean squared error was reduced but the peak signal-to-noise ratio of images was increased when fuzzy techniques were applied.

In such diseases as fatty liver, the surface of the liver appears brighter than the kidney tissue. So with image contrast improvement using the mentioned methods, the liver will be brighter and the kidney will be darker. Then, the liver surface can be easily separated from the kidney using the image segmentation methods. In this method, the output of ultrasound image of the improved fatty liver was segmented through fuzzy logic by image thresholding algorithms. In other words, after the implementation of contrast enhancement algorithms, images were converted to binary using otsu thresholding method; it is seen that the kidney takes the value of zero due tolower gray levels, and the liver surface and existing fats in the image take the value of one. The impact of each of the proposed algorithms is observed in image segmentation in Figure 5.

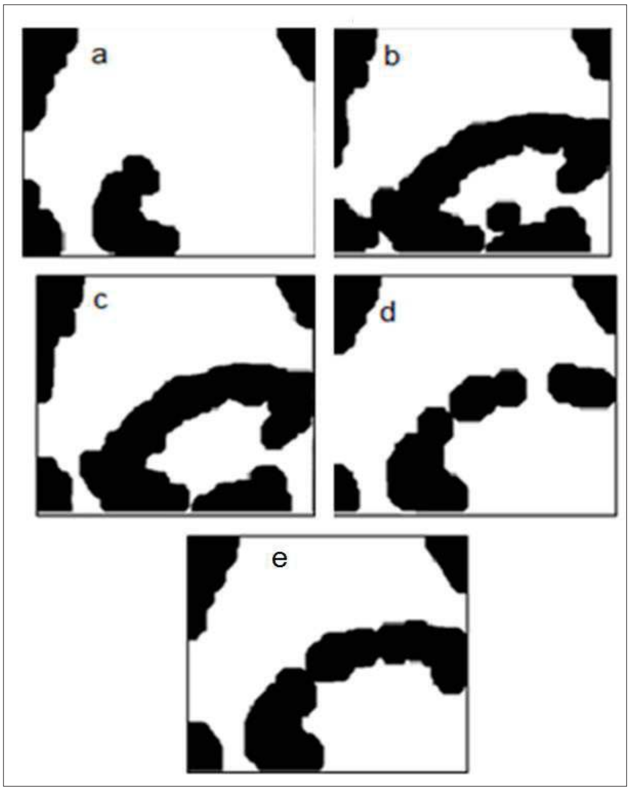

Figure 5. Comparison of image thresholding after the implementation of the proposed algorithms. From left to right: a: original image, b: after histogram equalization, c: after a fuzzy intensification operator, d: fuzzy histogram hyperbolization, e: after fuzzy rules.

4. DISCUSSION

In sonography images, quality improvement is considered an important issue in image pre-processing because of the low resolution and the difficulty in interpretations in the diagnosis of diffuse liver diseases. In performed studies to improve digital images quality, image processing techniques based on histogram correction (15) have been used to enhancement for also other sorts of images like digital mammogram images (16, 17) and mean squared error and peak signal-to-noise ratio (14) have often been used to compare the results. In addition to these indicators, image segmentation method has also been used in this study to compare the results of algorithms so that the effect of these methods as apre-processing will be uncovered at later stages of image processing. In other studies, fuzzy algorithms were used in breast sonography images for the detection of breast cancer (4) so that the quality and contrast of the final image were improved, and the data on the edges and texture of the image were better extracted using the fuzzy intensification operator algorithm. In another study, the effect of quality improvement of fuzzy ultrasound images of the liver to detect liver tumors (18) has been investigated. In this method, the diagnosis of the normal liver and livers of patients with cancerous tumors was carefully made using fuzzy methods of improving the quality of liver sonography images. These studies confirm the strength of fuzzy methods to improve the quality of sonography images.

In this study, improvement algorithms of liver ultrasound images were evaluated based on the three fuzzy techniques and were compared with one of the common methods of image processing. These methods not only improved the image contrast, but also led to the extraction of more information of ultrasound image and of liver region. Useful information for the diagnosis of diffuse liver diseases such as the fatty liver clearly increases, using fuzzy improvement of liver ultrasound images. Our findings show that fuzzy methods provide better results than conventional methods like histogram equalization do. Meanwhile, among the fuzzy methods for contrast enhancement studied in the research, the fuzzy intensification operator, resulted in signal-to-noise ratio and the mean squared error equal to 70.19 and 0.0062, respectively, which had the greatest impact on contrast enhancement of images. After carrying out this algorithm, extracting the liver from other organs like kidney was performed better, which revealed the strength of this algorithm more. In future studies, it is possible to use other image processing algorithms and fuzzy techniques such as noise removal, feature extraction, and image segmentation, which will increase the efficiency and improve the results of the methods studied in this research. Since image quality improvement is a problem-oriented issue (8), in addition to ultrasound images, it is possible to implement the proposed algorithms in other medical images such as MRI and to measure the power of these algorithms in other images. The obtained images have the capability to be used as input in automated decision support systems for the detection of liver diseases and can increase the accuracy and efficiency of these systems in the interpretation and diagnosis of diseases.

Among the limitations of this study was the lack of access to digital data stored in accordance with the DICOM (Digital Imaging and Communications in Medicine) standard format in the database of image processing research centers and imaging clinics. It took a long time to obtain this data bank and interact with related research centers.

5. CONCLUSION

In the study of diffused liver diseases, because of the low quality of ultrasound images, quality improvement as an important factor in the analysis of images was considered. Image pre-processing and application of powerful fuzzy techniques cause the accuracy and speed of later processing on images to increase. Therefore, the algorithms presented in this study can be used in ultrasound images of other organs as well as other formats such as MRI images to improve the quality. They can also be applied in ultrasound image processing systems.

- **Acknowledgements:** We use the opportunity to express our gratitude to the management and personnel of Digestive Disease Research Institute (DDRI) of Tehran University of Medical Sciences (TUMS) and Tehran Gastroentrology and Hepatology (Masoud Clinic), who greatly assisted us in our research.

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