A Fuzzy Model for Non-Linear Segment-Dependent Equalization of Radiographs Used to Detect Intraperitoneal Free Air

G. ANASTASSOPOULOS[1], I. STEPHANAKIS[2], A. J. KARAYIANNAKIS[3], D. MANTZARIS[1]and C. SIMOPOULOS[3]
[1] Medical Informatics Laboratory, Democritus University of Thrace, GR-68100, Alexandroupolis, GREECE

[2] Hellenic Telecommunications Organization, 151 81, Athens, GREECE

[3] Second Dept. of Surgery, Democritus University of Thrace, GR-68100, Alexandroupolis, Greece

Abstract: - Plain radiographs used in clinical practice in order to investigate the presence of intraperitoneal free air are equalized via a novel fuzzy equalization technique. Fuzzy segmentation of the image is performed according to the proposed procedure. The resulting regions of the image share overlapping boundaries as dictated by the shape of the valleys in the histogram of the image. A fuzzy membership function is extracted for each segment of the image and, sequentially, histogram equalization is carried out based on individual segment-dependent equalization functions. Specialized surgeons evaluate the enhanced images for their usefulness in making the diagnosis. The equalization results obtained using the proposed method compare favourably against the results obtained using global histogram equalization, i.e. when a unique equalization function is used for the entire image.

Key-Words: - Medical Image Enhancement, Image Segmentation, Fuzzy Methods

1 Introduction

Recent advances in technology have made efficient production, processing, transmission and storage of digital images an everyday reality. Digital images find a broad application in everyday clinical practice allowing for a better quality of the provided medical services. Nevertheless there are cases of medical images, especially plain radiographs, which are poor and non informative due to improper conditions during exposure. Noise and poor quality of an image due to insufficient contrast are frequent problems to be dealt with. To this end, novel methods of image enhancement have been developed.

Segmentation techniques constitute an important class of image processing methods [1][2][3]. A segmentation technique determines several regions of an image according to regional characteristics like the statistics of gray level pixel values or the correlation pixel colors. These characteristics are expected to be similar inside a segment of an image and distinct between different segments. There is a variety of methods to segment an image in order to obtain better post-processing results [3][4]. Fuzzy methods have found wide application in image processing and analysis in recent years [5][6][7]. Many algorithms for image processing that are based on fuzzy rules and fuzzy filtering have been developed. Such algorithms include fuzzy techniques for image restoration and noise reduction [8][9] as well as image segmentation. These methods apply theories developed in the context of signal processing and computer science [10]. The algorithm proposed in this paper allows for separate equalization of the different segments of plain abdominal radiographs. This facilitates the detection of free intraperitoneal air which is diagnostic for gastroduodenal ulcer perforation, a condition that requires emergency surgery. The method yields better results than conventional histogram equalization techniques, which derive the equalization transform function from the global histogram of the image.

2 Analysis of the Fuzzy Model Used for the Enhancement of the Medical Images

There are many image operators that can be applied to a medical image in order to improve its diagnostic information. Histogram equalization techniques may be used [11] whenever a uniform distribution of the pixel values of an image is required. These techniques are based on a non-linear transform that operates upon the pixels of an image without encompassing any local information about segment statistics. They produce an enhanced image with a (near) linear cumulative histogram over the entire dynamic range of the image. The following relation holds true for the equalized image denoted as $H(\mathrm{I}(m,n))$,

$$\Pr(k\Delta x \le H(I(m,n) < (k+1)\Delta x) = \text{constant} \qquad (1)$$

where $k\Delta x$ and $(k+1)\Delta x$ belong to the enhanced dynamic range of the image.

Enhancement of local contrast is required in medical images in which both highly illuminated and dark regions exist [11][12]. In such cases, histogram equalization techniques do not yield acceptable results and fail to point out any diagnostic information [13].

A fuzzy model is proposed in this paper in order to overcome the previous problem. The model assumes that the medical image is segmented into N regions R_i, i=1 … N, during an initial preprocessing step. Each region is characterized by its own histogram, $H_i(.)$, which yields a separate equalizing function [14]. A fuzzy membership function – denoted as $\mu_i(.)$ – is associated with each region so that,

$$\sum_{i=1}^{N} \mu_i(I(m,n)) = 1 \quad \forall \ (m,n) \qquad (2)$$

The overall equalized image is found as a fuzzy superposition of the equalized segments of the image,

$$H(I(m,n)) = \sum_{i=1}^{N} \left[L_i + \Delta c_i H_i(I(m,n))\right] \mu_i(I(m,n)) \qquad (3)$$

The continuity of the overall histogram has to be preserved. Consequently, the lower limit – denoted as L_i – and the higher limit – denoted as $L_i + \Delta c_i$ – of the pixel values of region R_i of the enhanced image are chosen in such a way that the continuity is ensured.

The proposed segment dependent fuzzy equalization is presented as a block diagram in Fig. 1.

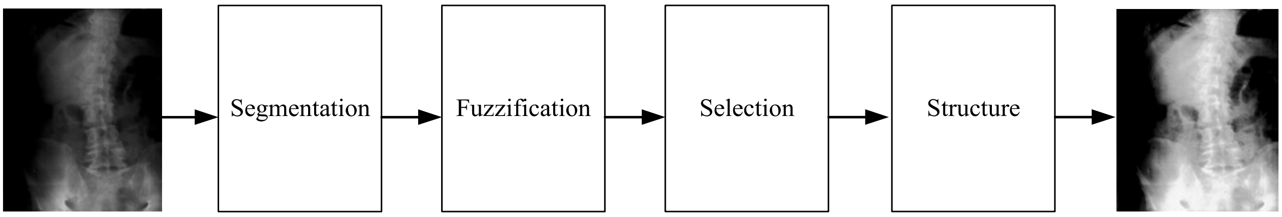

Fig. 1: Stages of segment-dependent fuzzy equalization

It consists of six distinctive stages. The original image is inputted during the first stage. Fuzzy segmentation and determination of the N segments of the original image are performed during the next stage. A rough set segmentation algorithm, like the one presented in [10], or fuzzy clustering algorithms for image segmentation [6] may be applied. Alternatively, the valleys of the global histogram of the image may be used to determine the N segments along the lines of [15] or via minimization of a fuzzy index [16]. The boundaries of the segments are fuzzy. Pixels at the boundaries are assigned to each segment according to a fuzzy membership function, μ_i, during the stage of fuzzification. The fuzzified histogram the image is taken from the regional membership according to the following relationship,

$$hist_i(k\Delta x \le I_i(m,n) < (k+1)\Delta x) = \sum_{k\Delta x \le I(m,n) < (k+1)\Delta x} \mu_i(I(m,n)) \ . \qquad (4)$$

The summation is calculated for the pixels of the image whose values lie within the selected interval. The histogram equalization functions for each segment of the image are determined during this stage. The stage of selection accomplishes a major purpose, i.e. the preservation of the continuity of the overall histogram. Mapping the fuzzified dynamic range of each segment to an output fuzzified dynamic range is critical and depends on the specific application. Physicians have to determine those segments of the image whose dynamic range needs to be enhanced. Segments with significant diagnostic information are allocated a wider dynamic range over against others that are repressed. The next stage of the proposed algorithm is structure. The equalization function is used, according to membership functions, for composition of final image. Finally, the equalized image is obtained by implementation of Eq. 3 as a weighted superposition of the segment equalization functions.

3 Materials

The medical imagery data, which are used at the suggested method, are obtained from medical database that has been developed in the Second Department of Surgery of the University Hospital of Alexandroupolis, Greece. This platform is employed:

- PC (Pentium4 – 1.80 GHz, 512 MBytes RAM, 40 GBytes / 7200 RPM Hard Disk)
- a Heidelberg Lynotype CPS Saphir/Opal Scanner, and
- a PC (Athlon XP – 2.5GHz, 512 MBytes RAM, 80GBytes / 7200 RPM Hard Disk) with a 64 MByte graphics card and a 22'' display monitor for viewing purposes.

All the equipment is connected via a Cisco Switch to the 100 Mbps intranet of Alexandroupolis' University Hospital.

Plain abdominal radiographs are used to apply the proposed enhancement methodology. In patients suspected to have perforation of a gastroduodenal ulcer, plain abdominal radiographs are taken with the patient in the upright position. The air escapes from the perforation freely into the peritoneal cavity and collects under the diaphragm. Typically it takes the form of a semilunar dark area limited between the right hemidiaphragm and the upper border of the liver or between the left hemidiaphragm and the rim of the gastric fundus. This image is characteristic of free intraperitoneal perforation of a gastroduodenal ulcer.

However, approximately 20% of patients with perforated gastroduodenal ulcer do not show free intraperitoneal air presumably because the adjacent omentum or other viscera seal the perforation before significant peritoneal air escape occurs. Technically poor radiographs because of miscalculated exposure conditions in these severely ill patients may also result in false negative images. The absence of free air in the abdomen especially in patients with atypical presentation may lead to a misdiagnosis. Since all patients with perforated gastroduodenal ulcer should undergo an emergency operation, it is extremely important to make the correct diagnosis. Therefore, false negative radiographs in which the free intraabdominal air is not visible due to technical reasons should be excluded.

In our study, after acquisition of the plain abdominal radiographs, the films are scanned with a Heidelberg Lynotype CPS Saphir/Opal scanner in multiple resolutions, in order to achieve the best image according to the directions of the surgeons.

4 Results

One of the original images that are examined is presented in Fig. 2. In this patient with clinically suspected perforation of a duodenal ulcer an upright abdominal plain radiograph was taken but no free air was visible under the diaphragm. The patient was critically ill with hypovolaemic shock, he had a previous cardiac bypass surgery and suffered from scoliosis. These conditions have affected the quality of the obtained radiograph and prevented a repeat examination. A small triangular shaped dark area is suspected above the upper border of the liver suggesting that valuable information for the diagnosis is contained within this region. The histogram of the original image is presented in Fig. 3. Enhancement results using a unique equalization function derived from the histogram of the image are presented in Fig. 4.

Fig. 2: Original image

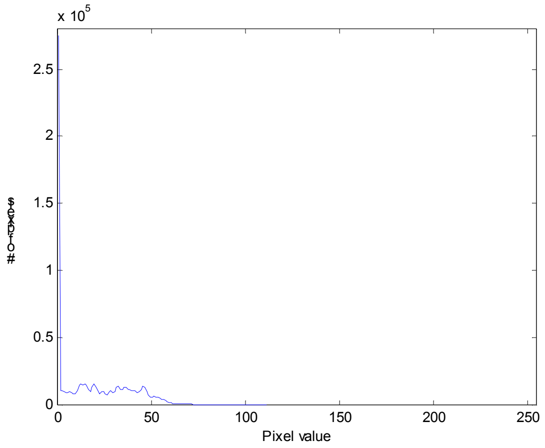

Fig. 3: Global histogram for the original image

The contrast of the image is slightly enhanced and the triangular shaped dark area above the upper border of the liver is more evident (upper left part of the image). Much better enhancement results are obtained by the application of the proposed enhancement algorithm. The proposed algorithm implements partitioning of the original image into two (*N*=2) regions [15]. Local means, which are derived from a window of 5x5 pixels, and local contrast, i.e. the difference between the pixel values and the local means, are enhanced using two separate equalization functions

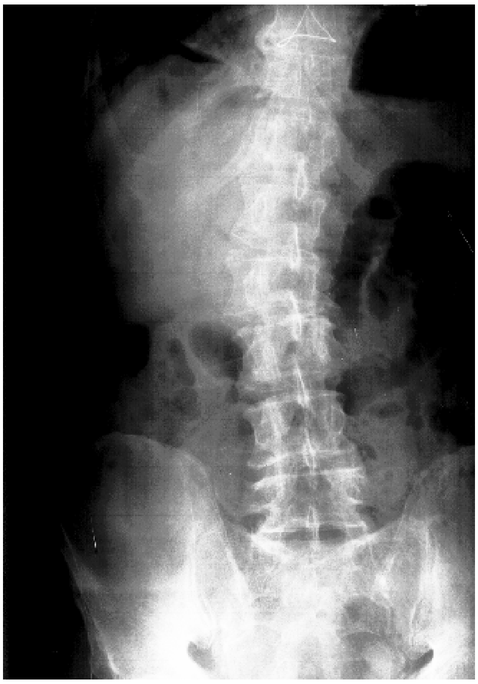

Fig. 4: Equalized image using global histogram equalization

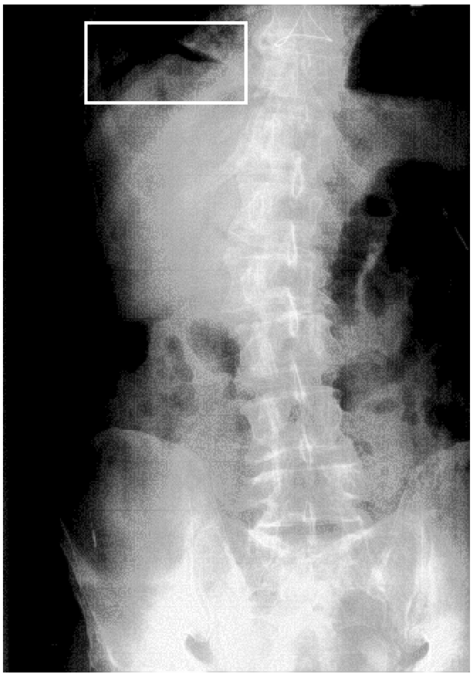

Fig. 5: Equalized image using the proposed method

for each segment of the original image. Fuzzy equalization is performed along the lines of Eq. 3 for both the local mean and the local contrast. Enhancement results are presented in Fig. 5. The region of interest is framed by a box. There is a distinct improvement compared to the original image and the enhanced image using the conventional technique. Free air is clearly visible under the right hemidiaphragm in the form of a typical semilunar dark area with clear demarcation from the diaphragm, the liver and the lower ribs. The picture is diagnostic of perforated duodenal ulcer.

The segmentation of the original image is based upon information obtained from its histogram. The two peaks of the histogram are assigned to the two different regions. Pixels with a value below 20 are assigned to *Region* 1 whereas pixels with a value above 30 are assigned to *Region* 2. Pixels with intermediate values are considered to inhere to the boundary between the two regions. The two segments of the image, which are obtained at segmentation stage, are presented in Fig. 6 and Fig. 7. The corresponding fuzzified histograms of the two regions are presented in Fig. 8 and Fig. 9 respectively. They are extracted by the application of Eq. 4 to both areas.

Fig. 6: Area 1 of the original image

Fig. 7: Area 2 of the original image

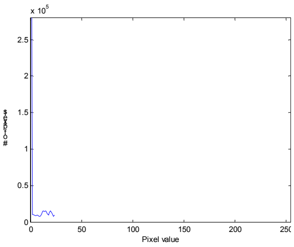

Fig. 8: Local histogram of Area 1 of the original image

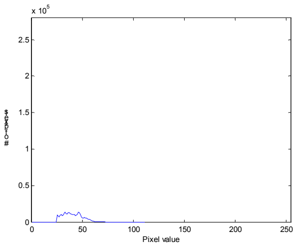

Fig. 9 : Local histogram of Area 2 of the original image

The cumulative histograms of the local means of the enhanced segments have to be linear (Eq. 1). The corresponding equalization functions are determined from this condition. The local means and the local contrast within each segment are equalized separately since this yields a better blend of the two regions at the boundaries. The equalization function for the local contrast corresponding to *Region* 1, which is the region of interest, enhances to a greater degree the dynamic range of the contrast ([-8 +8]) as compared to the equalization function for the local contrast corresponding to *Region* 2 ([-5 +5]). This is possible by the fact that the dynamic range of the pixel values of *Region* 1 before enhancement is smaller compared to that of *Region* 2. The original dynamic range of the contrast lies in general between –4 and +4.

The equalization functions for the local contrast and the local means corresponding to the two segments of the image are presented in Fig. 10 and Fig. 11 respectively. The overall equalization function for the local means, which results from the application of the proposed algorithm, is compared with the equalization function obtained from the global histogram of the image. The expansion of the dynamic range of *Region* 1 (from 0 to 190) and the simultaneous suppression of the dynamic range of *Region* 2 (from 191 to 235) are noticeable.

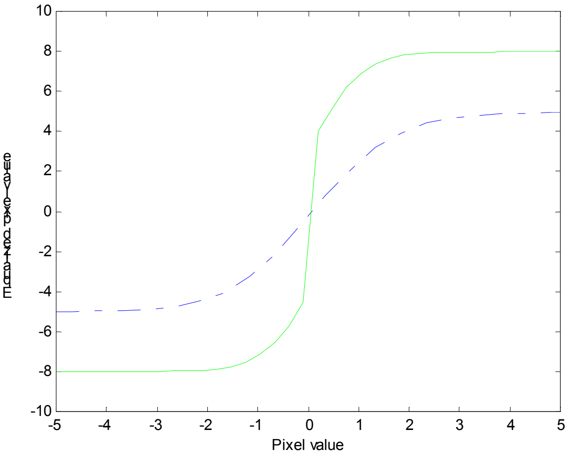

Fig. 10: Equalization functions resulting from the local histograms of the differential values for *Region* 1 (—) & 2 (– –)

Segmenting of the original image into more than two segments is possible, nevertheless no significant improvement of the original image is observed after enhancement.

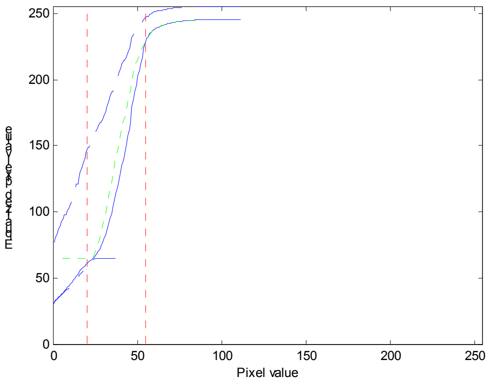

Fig. 11: Comparison between the equalization functions resulting from the global histogram (--) and the local histograms of the mean values for *Region* 1 (—) & 2 (– –)

5 Conclusion

This study presented a medical image enhancement method based on fuzzy theory and rules. The proposed algorithm provides satisfactory results comparing against conventional histogram equalization methods. This is due to the fact that each segment of the enhanced image is allocated a dynamic range according to the information that is meaningful for medical diagnosis and not the quantity of pixels belonging to that segment. The suggested method is independent of the number of segments. The algorithm is easily extended to cases in which the dynamic ranges of the individual segments are not consecutive.

References:

[1] A. Jain, Fundamentals of Digital Image Processing, *Prentice Hall*, London, 1989.

[2] R. C. Gonzalez, and P. Wintz, Digital Image Processing, *Addison-Wesley Publishing Company,* 1993.

[3] N. Pal, and S. K. Pal, A review on image segmentation techniques, *Pattern Recognition*, Vol. 26, No 9, 1993, pp.127–1294.

[4] B. Cramariuc, A. Moga, M. Gabbouj, Image segmentation by component labeling, *Proc. Int. Conf. Digital Signal Processing (DSP95)*, Limbassol, Cyprus, 1995, pp. 360-365.

[5] H. R. Tizhoosh, Fuzzy Logic in Image Processing, *Springer-Verlag*, Berlin, Germany, 1997.

[6] G. J. Klir, and B. Yuan, Fuzzy Sets and Fuzzy Logic, Prentice Hall, *Upper Saddle River, NJ,* 1995.

[7] B. Kosko, Global Stability of Generalized Additive Fuzzy Systems, *IEEE Trans. on Systems, Man, and Cybernetics—Part C: Applications And Reviews,* Vol. 28, No. 3, Aug. 1998, pp. 441-452.

[8] I. M. Stephanakis, G. Stamou, and S. Kollias, Piecewise Wiener Filter Model Based on Fuzzy Partition of Local Multiresolution Features for Image Restoration, *Proc. Int. Joint Conf. on Neural Networks (IJCNN '99),* Washington, D.C., July 1999.

[9] I. M. Stephanakis, G. Stamou, and S. Kollias, A Fuzzy Associative Operator for Enhancement of Noisy Images by Detection of Local Multiresolution Features, *Proc. 3rd Int. Conf. on Computational Intelligence and Neuroscience (ICCIN '98),* Research Triangle Park, North Carolina, Oct. 1998, Vol. II, pp. 4-7.

[10] S.K. Pal, and P. Mitra, Multispectral image segmentation using the rough-set-initialized EM algorithm, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 40, No 11, Nov. 2002, pp. 2495 –2501.

[11] G. Anastassopoulos, I. Stephanakis, and S. Gardikis, Evaluation of Histogram Enhancement Techniques Used in Conjunction With Wavelet Compression Methods For Improved Signal Processing Of Child Trauma Images, *Proc. 7th Australian and New Zealand Intelligent Information Systems Conference (7th ANZIIS)*, Perth, Western Australia, Nov. 2001, pp. 73-76.

[12] H. Atmaka, M. Bulut, D. Demir, Histogram based fuzzy Kohonen clustering network for image segmentation, *Proc. Int. Conf. Image Processing (ICIP96)* 1996, p. 18A6.

[13] G. Anastassopoulos, S. Gardikis and I. Stephanakis, Quality Assessment Of Child Trauma Images Compressed With Wavelet Compression Techniques In A Telemedicine Environment, *Proc. 4th Int. Conf. in Neural Networks and Expert Systems in Medicine and Healthcare*, June 2001, pp. 369-373.

[14] I. Stephanakis, G. Anastassopoulos, A. Karayiannakis, C. Simopoulos, Enhancement of Medical Images Using a Fuzzy Model for Segment Dependent Local Equalization, *Proc. 3rd Int. Symposium in Image and Signal Processing Analysis (ISPA03)*, Italy, Sep. 2003.

[15] H. D. Cheng, and Y. M. Lui, Automatic Bandwidth Selection of Fuzzy Membership Functions, *Information Sciences* 103, 1997, pp. 1-21.

[16] Liang-Kai Huang, and Mao-Jiun J. Wang, Image Thresholding By Minimizing the Measures Of Fuzziness, *Pattern Recognition*, Vol. 28, No. 1, 1995, pp. 41-51.