Automatic Threshold based Liver Lesion Segmentation in Abdominal 2D-CT Images

Asmita A. Moghe *aamoghe@gmail.com*
Department of IT University Institute of Technology
(Rajiv Gandhi Proudyogiki Vishwavidyalaya)
Bhopal, 462036, India

Dr. Jyoti Singhai *j.singhai@gmail.com*
Department of Electronics &Communication
Maulana Azad National Institute of Technology
Bhopal, 462051, India

Dr. S.C Shrivastava *scs_manit@yahoo.com*
Department of Electronics &Communication
Maulana Azad National Institute of Technology
Bhopal, 462051, India

Abstract

Liver lesion segmentation using single threshold in 2D abdominal CT images proves insufficient. The variations in gray level between liver and liver lesion, presence of similar gray levels in adjoining liver regions and type of lesion may vary from person to person. Thus, with threshold based segmentation, choice of appropriate thresholds for each case becomes a crucial task. An automatic threshold based liver lesion segmentation method for 2D abdominal CT pre contrast and post contrast image is proposed in this paper. The two thresholds, Lower Threshold and Higher Threshold are determined from statistical moments and texture measures. In pre contrast images, gray level difference in liver and liver lesion is very feeble as compared to post contrast images, which makes segmentation of lesion difficult. Proposed method is able to determine the accurate lesion boundaries in pre-contrast images also. It is able to segment lesions of various types and sizes in both pre contrast and post contrast images and also improves radiological analysis and diagnosis. Algorithm is tested on various cases and four peculiar cases are discussed in detail to evaluate the performance of algorithm.

Keywords: Segmentation, lesion, Thresholding.

1. INTRODUCTION

Imaging modalities like Ultrasound, MRI (Magnetic Resonance Imaging), CT (Computed Tomography) and PET (Positron Emission Tomography) are widely used techniques for liver lesion diagnosis. However, CT is ubiquitously available and preferred imaging modality among clinical practitioners. Abdominal CT images are segmented to determine different organs, the lesions in the abdominal organs and to provide 3D rendering of these organs.

The liver is the largest organ in the body. The contour and shape of the liver vary according to the patient habitus and lie [1]. Its shape is also influenced by the lateral segment of the left lobe and the length of the right lobe. The ribs cover the greater part of the right lobe and usually a small part of the right lobe is in contact with the abdominal wall. The right lobe is the largest of the four lobes of the liver and exceeds the left lobe by a ratio of 6:1. In an abdominal CT image of a healthy subject, the liver has uniform gray level. In the subjects with liver lesions, the gray level of lesion is different from the gray level of liver. This difference is better enhanced in corresponding contrast enhanced images. In clinical practice radiologists assess the lesion based on pre contrast images and the post contrast (contrast enhanced) images obtained for the same patient after injection of contrast either for diagnosis or for use during pre operative and/or intra operative surgery.

This peculiar property of variation in gray levels of liver and liver lesions can be used to isolate liver lesions from the liver. Isolating abdominal organs like liver from other organs in the abdomen or isolating liver lesion from the liver is accomplished using image segmentation. Segmentation is performed on the basis of gray level similarity or dissimilarity [2]. Based on dissimilarity point, line and edge, are detected but these features are not definite in abdominal CT images and difficult to locate. The lesions usually are closed curves and having a definite gray level range which is different from the liver as a whole, so regional segmentation methods based on similarity of gray levels are more suitable. Among these, region growing or region split and merge involve accurate selection of seed point, which is difficult to obtain. Hence in the proposed method thresholding technique is used to segment lesions present in liver. The size of liver, the variations in gray level between liver and liver lesion and type of lesion may vary from person to person. Thus, with threshold based segmentation, choice of appropriate thresholds for each case becomes a crucial task. Also, presence of similar gray levels in adjoining liver regions makes liver lesion segmentation further difficult and challenging.

Precise segmentation of liver lesions enhances manual analysis of radiographic images to assess impact and extent of lesion on neighbouring regions. Once the lesions become accessible, their invariant features like area, centroid etc can be obtained and used for further processing like image registration, image fusion etc. In this paper an automatic threshold selection technique based on statistical measures of CT images, is proposed to segment liver lesions in the pre contrast and post contrast image slices of the patient. The proposed automatic thresholding technique is tested on various types of lesions and segmented lesions accurately.
Literature related to liver segmentation is discussed in section 2, proposed automatic threshold based segmentation technique is explained in section 3, performance of proposed algorithm for different types of lesion is evaluated in section 4 and section 5 gives conclusion.

2. RELATED WORK

Organ segmentation in abdominal CT images is challenging due to beam hardening artifacts seen as focal areas of low attenuation near bones, partial-volume artifacts giving blurred images, streak artifacts due to patient movement, respiration etc. Lav R. Varshney [3] presented survey of various abdominal organ segmentation methods for CT scan images based on mathematical morphology, thresholding, neural network, level set methods, model fitting and data directed methods. Lav R. Varshney summarised limitations of different abdominal organ segmentation methods. Model based methods normally use rib cage as reference to obtain location of organs. Rule based methods make use of organ invariants. Morphological operations segment abdominal CT images well and are usually applied in combination with other methods [3]. Hepatic tissues from abdominal CT images have been classified using various texture measures [4]. In this method radiologist specifies the Region of Interest (ROI) (hepatic tissues) located in non enhanced images. Statistical measures are used to determine texture of ROI. Feature vectors of these ROI are formed, which are reduced using Genetic Algorithm. These feature vectors using five different kinds of neural networks, classifies ROI into four types of tissues. Neural Network (NN) based methods using texture of organs as features become ineffective in organ segmentation because organs themselves have substructures having different structures and texture may not be properly defined [4]. Also, neural network based methods need lot of training, which increases the complexity of the technique. Thresholding based methods have limited utility since various organs and tissues may have similar gray levels. Despite this, segmentation of contrast enhanced CT images, defined by a body box [5] strictly enclosing abdominal structures has improved the results. In [5] significant edges are determined in the three coronal, sagittal and axial slices to segment the heart volume so that information of only liver can be obtained from the images. This was required because the slices involved presence of heart and liver in them. Liver gray levels are estimated from histograms of the images. Major peak of histogram identifies liver region. First minima on either side of this peak give the minimum and maximum gray levels to segment the liver. This method is unable to isolate lesions from the liver. Moreover to segment liver lesions, a different set of thresholds are required as they have different gray levels compared to those of liver. In [6] a local multiphase C-V level set algorithm is integrated with multilevel Otsu's method to segment complicated liver lesion. Here points close to lesion are identified manually on the image to construct a local liver lesion image. Then lesion is pre segmented with multilevel Otsu's method. It gives the initial contour of lesion. Final contour of lesion is then obtained using multiphase C-V level set method. The method categorises the lesion into normal liver tissue, the enhanced part of lesion and the unenhanced part of lesion but formation of initial image of lesion requires points to be selected manually.

Soler et al [7], presented fully automatic anatomical, pathological and functional segmentation of liver from spiral CT scan images for hepatic liver surgery. In [7] all neighbouring organs like spleen, aorta, skin, bones etc are first delineated by use of information of histograms of specific regions. A model of the liver is then merged with that of segmented liver. Reconstructed liver provided information useful for pre operative surgery. This method also, isolates the liver from other organs but it is unable to isolate lesions within liver.

Region growing techniques are useful because they club pixels with similar gray levels but it is difficult to choose the seed pixel. In [8] automatic liver segmentation of contrast enhanced CT images is carried out. It uses an advanced form of region growing method and is able to segment liver parenchyma in most of the cases except where liver lesions are very large. Another texture based volumetric region growing method for liver segmentation in [9] finds seed point automatically and also the threshold for stopping the region growing process. In the pre processed 3D Abdominal CT images, seed point is chosen as the centre of CT volume and ROI is determined as abdominal pixels with orientation ranging between 90-120 degree from coordinates of abdominal centre of mass using a cost minimization approach. Local texture of neighbouring volume of seed pixel is determined from texture features, which are calculated from gray level co-occurrence matrix. Euclidean distances determine homogeneity between voxels with 6-connectivity. Every 6-neighbour voxel with euclidean distance below a threshold is included in the volume. Stopping threshold is a function of the Gaussian parameters as distance from seed to voxels is a Gaussian distribution. The method has been applied to both basal and arterial images but not for the same slice of the two images. This method gives under segmentation near liver boundaries.

Snake based liver lesion segmentation is useful for MR images [10]. In the MR images speckle is removed through median filtering and snake of liver contour is found by use of edges. Region is grown by the seed which is lesion pixel. Lesion boundary information is used for the snake model. Fuzzy edge information distinguishing lesion and liver region is used to modify the snake recursively to obtain accurate lesion boundaries. This method proves insufficient for high texture and low contrast content in images. In [11] watershed and active contour algorithms have been applied for segmentation to obtain volumetric information of hepatic liver metastases in CT images. Comparison of these algorithms showed that active contour algorithm is able to detect a good number of lesions compared to watershed algorithm. Segmentation errors occurred in case of lesions lying towards liver periphery. Watershed algorithm causes over segmentation. Over segmentation problem resulting due to use of watershed segmentation was considerably reduced in [12]. In this method watershed segmentation is applied to liver cancer lesion segmentation. Initially image gradient is found using sobel operator. Thresholding was done using Otsu's method followed by watershed segmentation to reduce its complexity. The segmented regions obtained are then merged by use of region adjacency graphs to merge most similar regions. Average gray scale and boundary average guideline are used as parameters to match the segmented regions. Though over segmentation problem of watershed segmentation is resolved to some extent, still threshold selection for region merging is dependent on manual expertise.
In all the segmentation methods discussed, segmentation of liver lesions is performed in very few cases and that too for a single type of lesion. Moreover both pre contrast and post contrast images are not considered for segmentation. In the next section an automatic thresholding technique based on statistical measures is proposed to segment different types of liver lesions in

both pre contrast and post contrast images. This segmentation is useful in determining feature points lying on the lesion boundary and within the lesion.

3. AUTOMATIC THRESHOLD BASED SEGMENTATION

The proposed method uses three steps Automatic thresholding, Morphological operations and Boundary extraction for segmentation in abdominal 2D-CT pre contrast and post contrast images. A flow diagram of the proposed method is as shown in Figure 1.

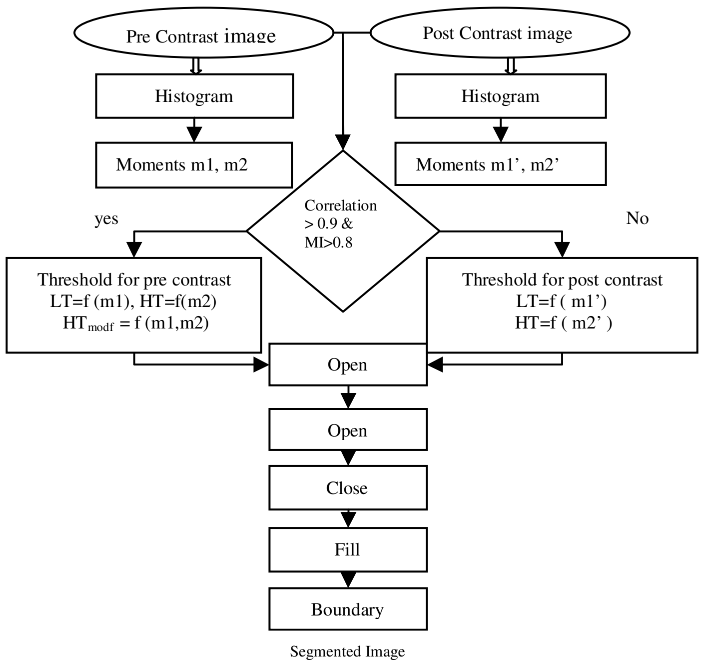


FIGURE1: Flow diagram of Automatic threshold based segmentation

3.1 Automatic Thresholding

It is observed that selection of a single threshold for segmentation of lesions in liver is not sufficient. The intensity of the entire liver region varies with respect to that of the liver lesions and type of lesion. A minimum of two thresholds are needed to segment liver and lesions from the abdominal CT images. A single threshold segments the liver as a whole and is incapable to segment lesions present in the liver. Paola et al [5] identified the patient body by using the minimum to the right of first gray level peak of the histogram of original image as threshold. Then body box defining the liver was obtained. The highest maxima of the histogram of this body box represent the liver and the first local minima lying on either side of the maxima represent gray levels corresponding to the liver. Paola et al [5] segmented liver but the method cannot segment lesions from liver. In this paper, an automatic threshold selection method is proposed to segment various types of lesions that can be present in a liver.

In the proposed method the lesions within the liver are determined using statistical measures. In the proposed algorithm the two thresholds used to segment lesions are called Lower Threshold (LT) and Higher Threshold (HT). The mean value of the image is used to determine LT and another statistical measure i.e. standard deviation is used to determine HT to segment the liver and lesion within the liver. These thresholds are minima lying on either side of the single gray level peak (P_G) of the histogram of the pre and post contrast slices for different patients with different types of lesions such as metastases, ascitis and multiple liver metastases and cyst. Precise calculation of these thresholds is crucial because they define the accuracy of segmentation of lesions, which in turn affect the accuracy of the results of further processing on segmented images. It is observed that, in most of the sets of pre contrast and post contrast images, number of maxima in pre contrast and post contrast images are equal and for such cases the HT lies to the right of P_G of the histogram, while the LT usually lies to the other side of P_G i.e. left of P_G. However exceptionally, when in the pre contrast images, the difference in gray level between liver and lesion is barely distinguishable and there is large difference in mean value of the pre contrast and the post contrast image slices, in such cases the LT and HT for post contrast image, both lie to the same side of P_G. In such cases the total number of maxima in the pre contrast and post contrast images is unequal and both the LT and HT lie to the right of the P_G. For these exceptional cases, the LT for pre contrast and post contrast image is kept same but the HT for pre contrast image needs modification.

In the proposed method, LT and HT are obtained from the statistical properties of the intensity histogram using statistical moments. Statistical moments are measures which provide the texture information [13]. The shape of histogram can be described by use of central moments μ_n defined in Eq (1)

$$\mu_n = \sum_{i=0}^{L-1} (z_i - m)^n \, p(z_i) \qquad (1)$$

In Eq (1) L is the number of possible gray levels, z_i is the discrete random variable indicating intensity levels in an image, n is the order of the moment and $p(z_i)$ is the histogram of the intensity levels in the region i.e. estimate of the probability of occurrence of intensity value z_i
LT is defined as twice the measure of average intensity of the histogram i.e. mean (m).

$$LT = 2m \qquad (2)$$

where mean (m) is expressed as

$$m = \sum_{i=0}^{L-1} z_i \, p(z_i) \qquad (3)$$

HT is defined as twice of the measure of average contrast i.e. standard deviation (σ),

$$HT = 2\sigma, \qquad (4)$$

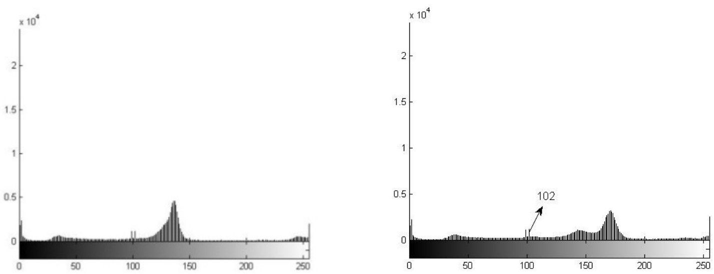
standard deviation σ is given as in Eq(5)

$$\sigma = \sqrt{\mu_2(z)} = \sqrt{\sigma^2} \qquad (5)$$

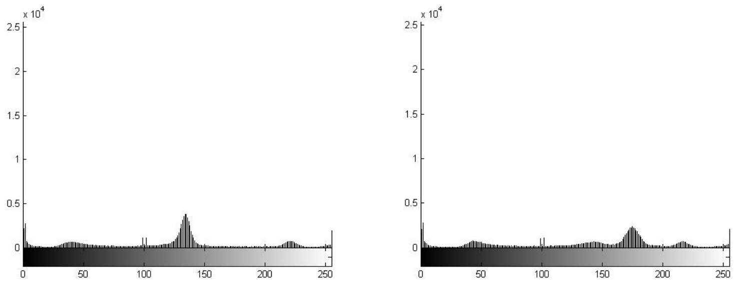
In exceptional cases for which number of peaks in the histograms of pre and post contrast image slices of patients are unequal, HT for pre contrast image is modified to HT_{modf} as given in Eq(6).

$$HT_{\mathrm{mod}\,f} = 2LT - \frac{(HT - LT)}{2} \qquad (6)$$

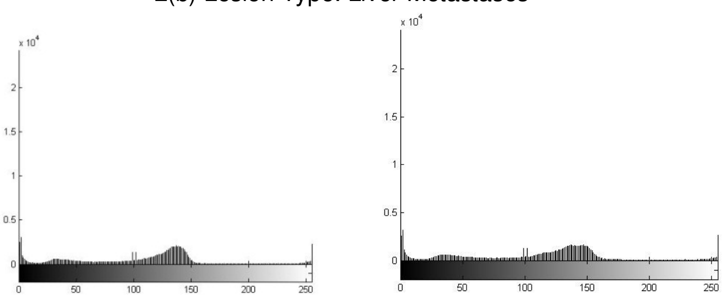
This can be explained through the histograms for the selected slices of few cases (patients) suffering from ascitis, liver metastases and multiple liver metastases and cyst. Histograms of chosen slices of these patients are shown in Figure 2.



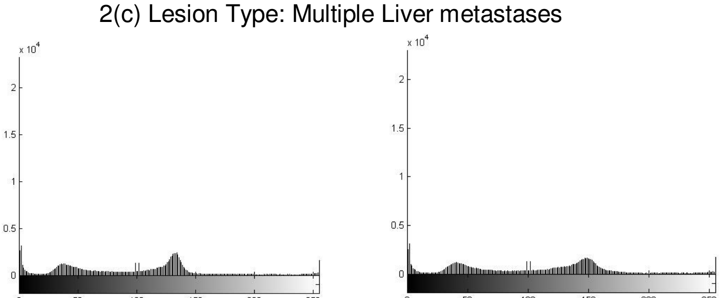
2(a) Lesion Type: Ascitis



2(b) Lesion Type: Liver Metastases



2(c) Lesion Type: Multiple Liver metastases



2(d) Lesion Type: Cyst

FIGURE2: Histograms of Pre contrast images (left column) and Post contrast images (right column) for different types of lesions in patients p1-p4. 2(a) ascitis: patient p1, 2(b) liver metastases: patient p2; 2(c) multiple liver metastases: patient p3; 2(d) cyst; patient p 4

In Figure 2, histograms in the left column are of pre contrast image slices and histograms in the right column are of post contrast image slices of the patients p1-p4. In the pre and post contrast images of most cases, the thresholds LT and HT calculated according to proposed method are seen to lie on either side of the single peak (P_G) in the histogram appearing at a gray level of 102 i.e. LT lies to the left of P_G and HT lies to the right of P_G. However, as identified earlier, there are some exceptional cases, when LT and HT both lie on the same side of P_G. This can be seen in histograms of Figure 2(a) and Figure 2(b). Here both LT and HT for post contrast image, lie to the right of P_G (102) because of the large difference in mean value of the pre contrast and the post contrast image slices. In the slices of histograms of pre contrast images in Figure 2(a) and Figure 2(b) the gray level differences between liver and lesion is barely distinguishable whereas for slices of histograms of pre contrast images in Figure 2(c) and Figure 2(d), the gray level difference in liver and lesion is considerable. Thus the threshold levels for pre contrast images of Figure 2(a) and Figure 2(b) is different from that for Figure 2(c) and Figure 2(d). All these commonly indicate feeble difference in gray level of liver and lesion. It is also observed that the number of maxima in the histograms of the pre and post contrast images in Figure 2(c) and Figure 2(d) are equal whereas in Figure 2(a) and 2(b) are unequal. This is attributed to the availability of relatively less gray levels in pre contrast image and more gray levels in post contrast images for patient p1 and patient p2. In addition a higher correlation and higher Mutual information between the pre and post contrast images is seen (above 0.9 and above 0.8 respectively) along with large value of mean for the images for p1 and p2, as shown in Table 1. In case of patient p3 and patient p4, the number of gray levels in pre and post contrast images being relatively same, and histogram peaks are also equal in number.

Patient	Correlation	Mutual Information	Mean (pre contrast)	Mean(post contrast)
p1	0.9430	0.8839	50.0388	58.9335
p2	0.9106	0.8451	45.1442	51.9194
p3	0.6769	0.7581	43.4805	45.4769
p4	0.8761	0.8747	41.5193	45.9020

TABLE 1: Correlation coefficient and Mutual Information of pre and post contrast images for patients p1-p4

Hence modification in HT according to Eq (6) has been suggested for those pre contrast images for which correlation coefficient is above 0.9, Mutual Information above 0.8 and it has a higher mean value. In pre contrast images i.e. Figure 2(c), 2(d); HT is calculated according to Eq (5). In all post contrast images LT is calculated according to Eq (3) and HT is calculated according to Eq (5) only. The Lower threshold (LT) and Higher threshold (HT) calculated using proposed method for each patient are as given in Table 2.

Patient	Pre Contrast			Post Contrast	
	Lower Threshold (LT)	Higher Threshold (HT)	Modified Higher Threshold (HT_{modf})	Lower Threshold (LT)	Upper Threshold (HT)
p1	100.0776	141.3447	131.0279	117.8670	157.9767
p2	90.2883	140.5499	127.9845	103.8389	156.481
p3	86.9609	127.9678	Not Applicable	90.9538	133.1248
p4	83.0385	122.5669	Not Applicable	91.8039	132.2971

TABLE 2: LT and HT for pre and post contrast images

Using this proposed automatic thresholding for 2D abdominal CT images it is seen that apart from segmented lesions, those regions of the abdomen that have similar gray levels as the gray levels of lesions are also segmented. The region of interest however is the liver. So the geometrical location of liver is considered and inter patient variations in size of the liver are taken into account to determine the region of interest. The regions other than liver that are segmented are masked by choosing a definite boundary box which does not include the entire abdomen as in [5] but encloses only the region to the left of aorta containing the liver as shown in Figure 3. Usually region between the coordinates (100:300) and (100:250) correctly encompass the right lobe of the liver.

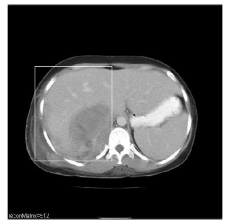


FIGURE 3: Boundary box enclosing the liver

The image thus obtained after masking now contains only the lesions in the liver mainly with a little segmentation seen beyond the rib cage. After thresholding some morphological operators are applied.

3.2 Morphological Processing

Morphological operations involve two rounds of ‘opening’ followed by’ closing’, then a ‘fill’ operation followed by ‘majority’ operation. Morphological opening completely removes regions of an object that cannot contain the structuring element, smoothes inside of object contours, breaks thin connections and removes thin protrusions [3]. This elimination of certain connections removes some small segmented regions which are not the lesions. It filters details and simplifies image by rounding corners. Morphological closing tends to smooth contours of objects. Unlike opening however, it joins narrow breaks, fills long thin gulfs and fills holes smaller than the structuring element. The ‘fill’ operation fills the isolated individual pixels. ‘Majority’ operation sets a pixel to 1 if 5 or more pixels in its 3x3 neighbourhood are 1 else it sets the pixel to 0. After application of morphological operators, the lesions are then identified by precise boundaries obtained using boundary detection.

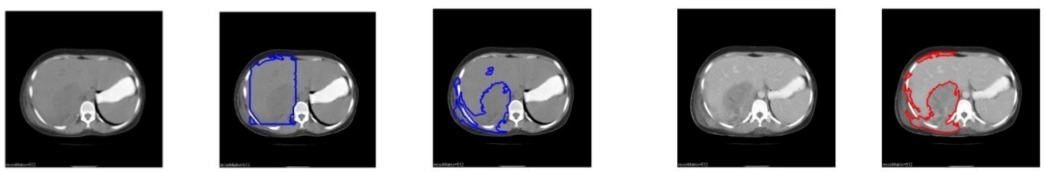
3.3 Boundary Detection

The boundaries of lesions after Morphological Processing are determined using ‘bwboundaries’ function in MATLAB. This function traces the exterior boundaries of objects, as well as boundaries of holes inside these objects, in the binary image. Liver lesions are of different types with different shapes and size. Hence two thresholds are needed to define them distinctly. From the set of images under consideration, it is observed that in order to identify liver lesions having very small size as in case of liver metastases and multiple liver metastases, in the proposed method boundary lengths greater than 2 of lesion are considered as threshold. However for lesions with large sizes as in case of ascitis, enlarged liver etc. boundary lengths greater than 200 are used as threshold for segmentation. These thresholds for boundary length are found by experiments carried out over a large number of images.

4. RESULTS

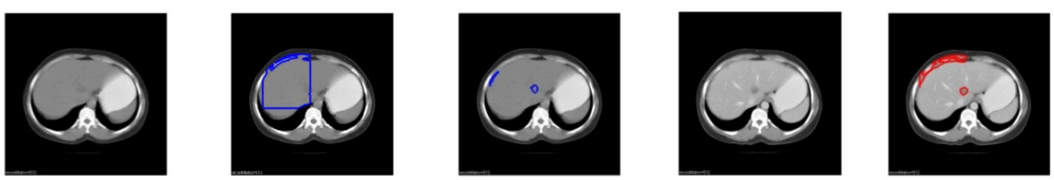
The proposed method is tested on 20 image slices of 2D abdominal CT images having varied liver lesions like liver metastases, ascitis, cyst and multiple liver metastases. The single slice spiral CT, axial images are taken from WIPRO GE CT/e machine. The images are in DICOM format and exported to .JPG format using e-Film 1.5.3 workstation. These images are converted to gray scale images to provide a set of 2D slices of size 512x512 with slice thickness 10mm. Number of slices per patient varied from 20 to 58. The experiment was performed on 32 bit, 2GHz. Intel Core 2 Duo processor using MATLAB. In each patient, corresponding slice of pre contrast and post contrast image is selected to segment the liver lesions. No pre processing is required to implement the proposed algorithm. The LT and HT for pre contrast and post contrast images in each patient are determined according to the proposed method. Boundaries of segmented lesions in both pre contrast and post contrast images of all patients are depicted as in Figure 4 -7

Analysis of segmented lesions of pre and post contrast images of the four peculiar cases (patients) is done to evaluate the performance of the proposed algorithm, of which pre contrast images of 2 patients need modification in HT and pre contrast images of 2 patients do not need modification in HT. In Figure 4 and Figure 5, pre contrast images p1(a) and p2(a) of patient 1 and patient 2 having ascitis and liver metastases are shown. These images are segmented using LT and HT, the segmented regions so obtained are shown in blue in p1(b) and p2(b), which are segmenting entire liver region and unable to show segmented lesions. However when these images are segmented using LT and HT_{modf} according to the Eq(6) and as per the requirement for modification in threshold suggested in pre contrast images when correlation coefficient of pre and post contrast images is greater than 0.9 amd mutual information (MI) above 0.8, then the lesions are clearly segmented in these pre contrast images which are shown in p1(c) and p2(c). The segmented regions in image p1(b) and p1(c), p2(b) and p2(c) clearly indicate the requirement of modification in HT of these pre contrast images. The post contrast images of the same patients are shown in p1(d) and p2(d). Segmented lesions on these post contrast images using LT and HT as per the proposed algorithm are shown in red as in p1(e) and p2(e)



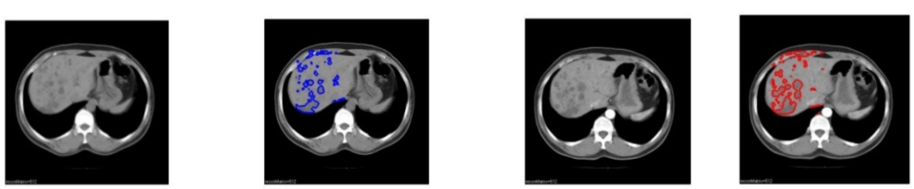
p1 (a) p2 (b) p1 (c) p1 (d) p1 (e)

FIGURE 4: Details of patient p1: (a) Pre contrast image (b) Boundaries of lesions segmented with LT, HT in pre contrast images (c) Boundaries of lesions segmented with LT, HT_{modf} in pre contrast images (d) Post contrast images (e) Boundaries of lesions segmented with LT,HT in post contrast images



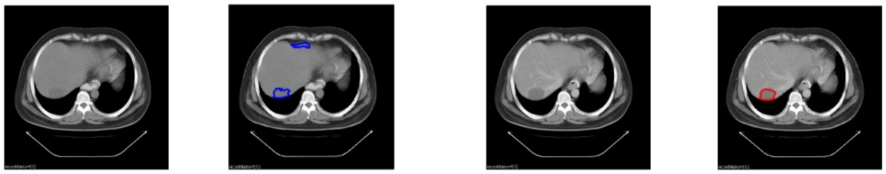
p2 (a) p2 (b) p2 (c) p2 (d) p2 (e)

FIGURE 5: Details of patient p2: (a) Pre contrast image (b) Boundaries of lesions segmented with LT, HT in pre contrast images (c) Boundaries of lesions segmented with LT, HT_{modf} in pre contrast images (d) Post contrast images (e) Boundaries of lesions segmented with LT,HT in post contrast images



p3 (a) p3 (b) p 3 (c) p 3 (d)

FIGURE 6: Details patient p3 (a) Pre contrast images (b) Boundaries of lesions segmented with LT, HT in pre contrast images (c) Post contrast images (d) Boundaries of lesion segmented with LT, HT in post contrast images



p4 (a) p4 (b) p4 (c) p4 (d)

FIGURE 7: Details of patient p4. (a) Pre contrast images (b) Boundaries of lesions segmented with LT, HT in pre contrast images (c) Post contrast images (d) Boundaries of lesion segmented with LT, HT in post contrast images

In figure 6 and Figure 7 pre contrast images of patients p3 and p4 with multiple liver metastases and cyst are shown in p3 (a) and p4 (a) respectively. These pre contrast images are segmented using LT and HT and the segmented lesion boundaries on the respective pre contrast images are shown in blue in p3 (b) and p4 (b) . The post contrast images for patients p3 and p4 are shown in p3 (c) and p4 (c). These post contrast images are segmented using LT and HT and segmented lesion boundaries are shown in red on respective post contrast images in p3 (d) and p4 (d). These observations clearly show that within the defined boundary box, similar lesions in both pre contrast and post contrast images can be readily obtained by the proposed segmentation method. The lesions detected by the proposed method of segmentation can assist in precise determination of feature points. Feature points like Hull points of segmented regions and their centroids which are invariant to translation and rotation of segmented post contrast image. For illustration these have been shown only for patient p2 are as shown in Figure 6.

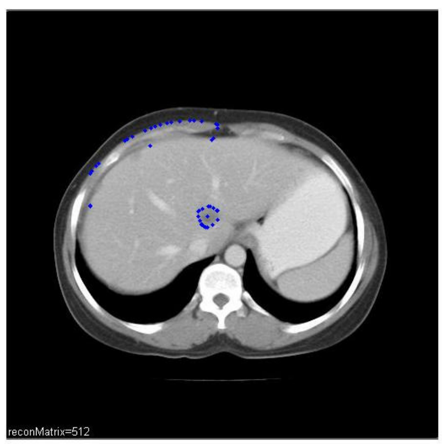


FIGURE 6: Hull points and centroid of segmented lesion

5. CONCLUSIONS

An automatic threshold based proposed method is able to segment pre contrast and post contrast abdominal 2D CT images having varied types of lesions like liver metastases, ascitis and cyst more accurately. LT and HT are used to segment the lesions from the liver. In some cases, pre contrast images have very feeble difference in gray levels of liver and liver lesions but for some cases pre contrast images show relatively larger gray level difference. Proposed HT modification in pre contrast images with feeble gray level difference in liver and liver lesion enhances visual assessment of liver lesion in pre contrast images. The objective of the paper to locate lesion boundaries to find feature points on and within the lesion for further processing is accurately accomplished. The lesions are commonly identified in both the pre contrast and post contrast images in each patient. A boundary box is used to restrict the region of interest. This boundary box can be used in future for segmenting lesions of surrounding anatomy.

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