IMAGE PREPROCESSING OF ABDOMINAL CT SCAN TO IMPROVE VISIBILITY OF ANY LESIONS IN KIDNEYS

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ABSTRACT

Abdominal CT scan images are widely used in detection of kidney lesions. This paper study is conducted for pre-processing abdominal CT scan images so as to segment the kidney for further analysis of lesion detection. Various noise filters and segmentation techniques have been experimented to select the best filter and segmentation techniques for pre-processing the CT image. The experimental study finds a combination of Median filter followed by Wiener filter more effective to remove different noises present in the CT images. Different segmentation techniques have been run on the test data set of CT images and it is observed that Edge based active contour produced better results than Graph Cut and region based active contours.

Keywords: *Medical Imaging, Noise Filters, Segmentation, Active Contour, Region-based, Edge-based, Graph Cut.*

1. INTRODUCTION

Kidneys are vital organs of human anatomy which helps in filtering and removing waste products from the blood. Statistics on kidney diseases reveal that cases of kidney cancer have been growing every year and is in the top list of cancers being detected. However, the survival rate increases if detected in early stages and proper treatment is given. Clinical observations along with medical imaging plays a key role in the diagnosis of kidney cancer. The imaging techniques help radiologists in identifying the exact location, size and type/grade of the cancer. Various medical imaging modalities like CT - Computed Tomography, MRI - Magnetic Resonance, US - Ultrasound, other nuclear imaging techniques like PET- Positron Emission Tomography and SPECT - Single Photon Emission Computed Tomography are available for medical imaging. CT images are extensively used in medical diagnosis for its affordability, availability, non-invasive, non-intervention, multi-parameter imaging with better resolution.

In this paper, we study about preprocessing the abdominal CT scan image so as to help in segmenting the kidneys and detecting the lesions present in the kidney for further analysis and in treatment required to be given to the patient. The preprocessing includes noise filtering, contrast enhancement and segmentation. In this paper, we study various noise removal and segmentation algorithms in CT images and make a comparative study between them. The abdominal CT image contains various organs like liver, spleen, kidney, colon, pancreas, duodenum, inferior vena cava etc. Segmentation of kidneys from abdominal CT scan image is a challenging task as most of the organs in the abdominal CT image are soft tissues with no clear borders. Graph cut, Region based and Edge based active contour segmentation methods are studied in this paper.

2. RELATED LITERATURE STUDY

The work in this paper relates to noise removal and kidney segmentation from abdominal CT images

Kidney lesion do not show symptoms and are detected accidentally from CT scans taken for other ailments. From literature, it is noticed that not much

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work in done on Kidney lesion detection in abdominal CT images. Noise is induced into the CT scan images due to the CT artifacts, improper focus, motion etc. It is very important to remove noise before segmentation of the images. Most common noises that are seen in CT images are Salt and Pepper noise, Speckle noise, Gaussian noise [4,9]. Extensive research has been done for removing noise from the images. The important consideration for selection of noise filter is complete noise removal while preserving edges. Kaur et al. [10] presented performance of various noise filters – Gaussian, Wiener, Mean, Median filters. Sonali et al. [4] have used various filters for preprocessing the image and have proposed median filtering for removing film artifacts. Kumar et al. [6] have proposed use of Median and Weiner filter for removing Salt and Pepper noise and Gaussian noise present in the non-medical images. The paper concludes that Weiner filter works well with Gaussian and speckle noises and Median filter works well with salt and pepper noise. PSNR [4] and MSE [8] are studied in various papers for measuring image quality metrics. Wang et al. [2] has proposed using of metric based on structural similarity, SSIM for image quality assessment.

Another important work in this paper is segmentation. Kidney segmentation from CT scan images is always a challenge as there are many soft tissues with similar intensity surrounding the kidney with unclear borders. Active contours and graph cuts have proved to give promising segmentation results for kidney segmentation. The concept of active contour was first introduced by Kass et al. [17] where contour was evolved for object detection using the energy terms. Since then lot of research has been done on active contours for detection of object boundary. Chan et al. [14] have proposed active contours without edges based on curve evolution techniques, the Mumford-Shah functional for image segmentation and the level sets. This technique handles topology changes well compared to the normal snakes. V. Caselles et.al. [15] have proposed geodesic formulation in active contours for effective boundary detection of objects taking advantage of the gradient differences. A new energy term is introduced to additionally pull the deforming curve towards the boundary of the object. Lei et al. [13] have performed a comparative study of various deformable contour (balloon, topology, distance, gradient vector flow, Geodesic active, etc) methods on various modalities of medical image segmentation, where he suggests that the methods are not mutually exclusive and could be used in combination for better segmentation results depending on the application. Also the authors recommend incorporation of image or object information into the framework which yields better segmentation results. Kolomaznik [18] has proposed a fast segmentation using both region and edge energy terms where the first phase of segmentation is controlled by statistical shape parameters and the next phase of segmentation is controlled by the image data. Another segmentation technique in the recent years is the graph-cut framework, which applies graph theory for fast segmentation of an image into foreground and background. Anders P. et al. [16] have included prior information obtained from terminal node weights and learning algorithms into the graph cut method to produce efficient segmentation results.

For detection of kidney lesions, it is important to first segment the kidney from the abdominal CT image and then identify the lesion. CT images usually come with noise and can impact the segmentation results. Hence it is very important to remove noise and then segment the kidney for further analysis of kidney lesions. Abdominal CT images consists of many other organs with the same intensity as that kidney and normal segmentation methods used for segmentation of other organs do not perform well with kidney segmentation. So segmentation techniques using active contours and graph-cut are implemented and a comparative study is performed.

Various noise removal filters and image segmentation techniques have been applied in our work to select the best suitable techniques for abdominal CT images. In the next sections, we are going to deal with various noise removal algorithms and segmentation algorithms in CT images.

3. METHODOLOGY

The proposed methodology of Kidney Cancer detection consists of 4 main phases, Image acquisition, preprocessing of the image to segment kidneys from abdominal CT images, feature extraction from the segmented kidneys, lesion identification and classification. Preprocessing is an important step in our methodology and results of the next phases is highly dependent on the preprocessing phase to produce accurate results in feature extraction, lesion detection and classification phases.

Preprocessing phase consists of noise filtering, contrast enhancement and kidney segmentation. The work in this paper is limited to noise removal

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algorithms and kidney segmentation techniques only. The other techniques used for the remaining phases will be discussed in subsequent work.

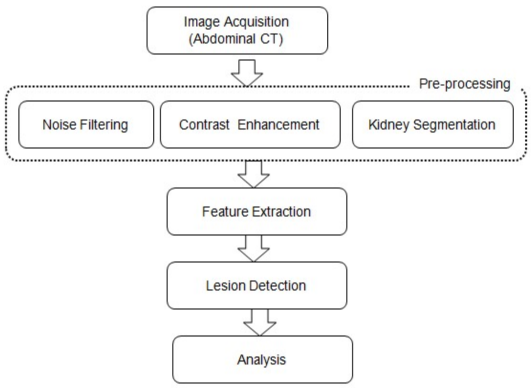

Figure:1 Proposed Kidney Cancer Detection Workflow

The research work in this paper aims to find one common suitable noise removal filter for various noises present in the CT image and a suitable kidney segmentation technique that works for images with contrast and without contrast.

MATLAB tool is used throughout the work conducted in this paper.

4. NOISE FILTERING

Noise can cause improper segmentation results and hence it is very important to remove the noise before segmentation. Common noises in CT images are Salt and Pepper noise, Speckle noise, Gaussian noise [1,4,5,9]. Noise can be removed from images using various filters like Mean filter, Gaussian filter, Median filter and Weiner filter, etc.

Mean filter is a linear filter and uses the averaging phenomenon over the neighbourhood region, while Median filter is a non-linear filter and each pixel intensity value in the image is replaced by the median of the pixel intensity values in the selected neighbourhood of the filter [9]. Wiener filter is based on statistical methodology and eliminates the additive noise while preserving the edges and also inverts the blur at the same time [1]. Gaussian filter performs convolution both in spatial and frequency domain and popularly known for blurring and reducing noise by smoothing the data. A new combination filter, Median followed by Wiener filters has been proposed [3, 6] to remove noise. The Median filter helps to remove impulsive noise while the Wiener filters removes both the blur and additive white Gaussian noise in the image while preserving the edges. Performance of the filters can be measured using image quality assessment metrics such as Mean Squared Error (MSE), Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSIM). For a good quality image, MSE value should be lower and PSNR and SSIM should be higher.

5. NOISE SIMULATION AND ANALYSIS

Experiment has been conducted to study the best filter for noise filtering against different noises present in CT images. For the purpose of study, noise has been added to the acquired images and different filters have been applied sequentially. Below flow diagram depicts the steps involved in applying various noise filters and measuring the image metrics.

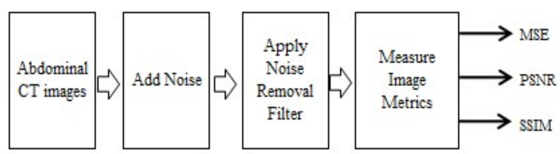

Figure:2 Simulation process of applying noise filters and measuring image quality metrics

Experiment study of various noise filters on each of the noises (Salt and Pepper noise, Gaussian noise, speckle noise) is conducted on a test data set of abdominal CT images (both with and without contrast). The noised filtered images and computed values of MSE, PSNR and SSIM from the noise filtered images are presented below.

MSE, PSNR and SSIM are measured on the output images and then the average values are computed and presented in the below tables.

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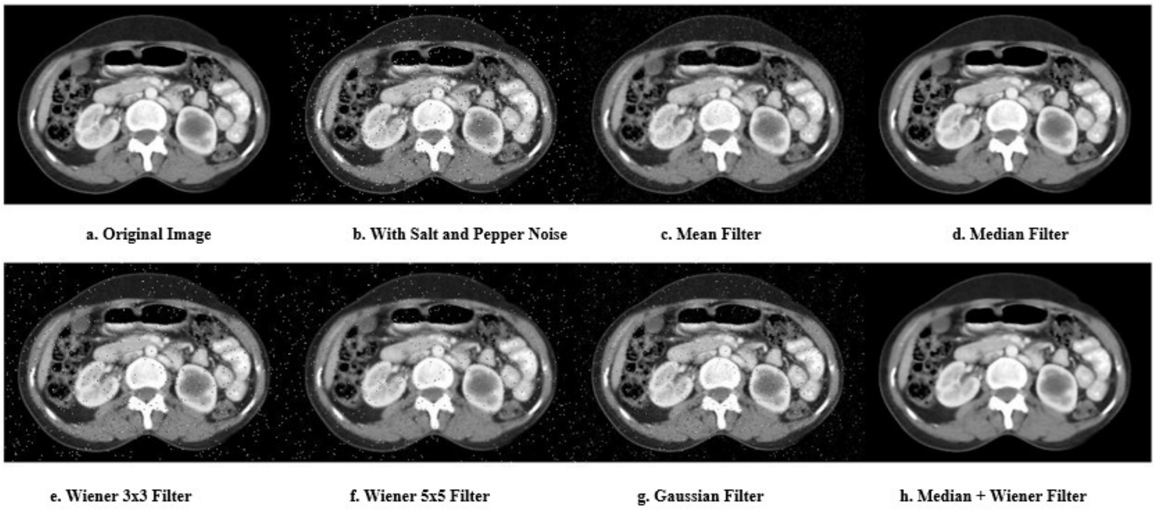

Figure:3 a) Original Image b) Image simulated with Salt and Pepper Noise. Images after applying: c) Mean filter, d) Median filter, e) Wiener 3x3 filter f) Wiener 5x5 filter g) Gaussian Filter h) Median followed by Wiener filter

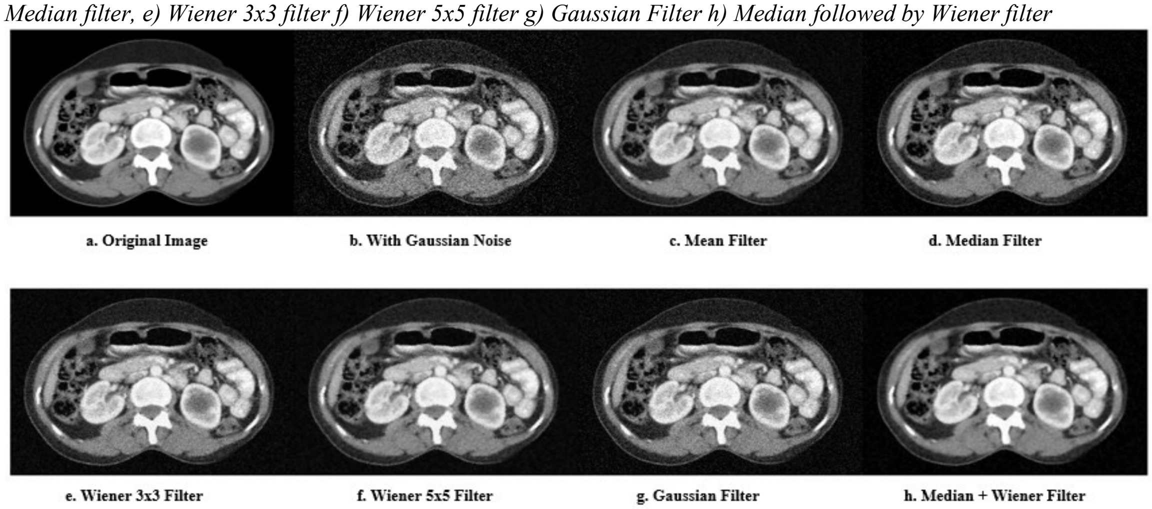

Figure:4 a) Original Image b) Image simulated with Gaussian Noise. Images after applying: c) Mean filter, d) Median filter, e) Wiener 3x3 filter f) Wiener 5x5 filter g) Gaussian Filter h) Median followed by Wiener filter

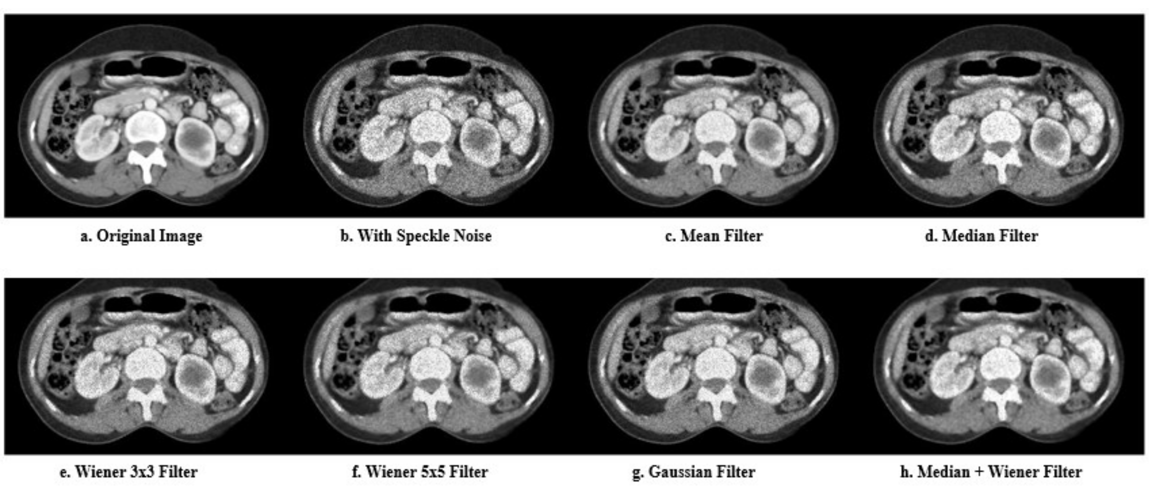

Figure:5 a) Original Image b) Image simulated with Speckle Noise. Images after applying: c) Mean filter, d) Median Filter, e) Wiener 3x3 filter f) Wiener 5x5 filter g) Gaussian Filter h) Median followed by Wiener filter

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Table 1: Comparison of Image Metrics after simulating Salt and Pepper noise and applying various filter algorithms

Performance Parameters with various Filters for Images with Salt and Pepper Noise			
Noise Filters	**MSE**	**PSNR**	**SSIM**
Mean Filter	70.15	29.59	0.770
Median Filter	9.95	39.87	0.983
Wiener3x3 Filter	390.71	22.22	0.632
Wiener5x5 Filter	264.64	23.92	0.675
Gaussian Filter	206.58	24.99	0.686
Median Filter + Wiener Filter	20.52	35.90	0.935

Table 2: Comparison of Image Metrics after simulating Gaussian noise and applying various filter algorithms

Performance Parameters with various Filters for Images with Gaussian Noise			
Noise Filters	**MSE**	**PSNR**	**SSIM**
Mean Filter	101.60	28.08	0.553
Median Filter	100.71	28.25	0.579
Wiener3x3 Filter	153.84	26.38	0.474
Wiener5x5 Filter	113.05	27.73	0.556
Gaussian Filter	232.53	24.47	0.366
Median Filter + Wiener Filter	55.76	30.82	0.708

Table 3: Comparison of Image Metrics after simulating Speckle noise and applying various filter algorithms

Performance Parameters with various Filters for Images with Speckle Noise			
Noise Filters	**MSE**	**PSNR**	**SSIM**
Mean Filter	55.02	30.97	0.867
Median Filter	89.91	28.70	0.794
Wiener3x3 Filter	114.11	27.64	0.784
Wiener5x5 Filter	91.78	28.59	0.806
Gaussian Filter	125.27	27.28	0.748
Median Filter + Wiener Filter	54.92	30.85	0.869

From the experimental findings, it is observed that for Salt and Pepper noise, Median filter works best followed by the combination filter (Median followed by Wiener filter). Both filters have lesser MSE and higher PSNR and SSIM values compared to other filters. For Gaussian and Speckle noise, combination filter produces better results in noise removal. Hence combintaion filter (Median followed by Wiener filter) is recommended as the best filter to remove noise as it produces good results for all kinds of noises present in the considered CT images.

6. KIDNEY SEGMENTATION

Segmentation is an important step in medical image processing. It helps to partition the region of interest from the CT image for further analysis. As most of the organs including kidney are soft tissues with unclear borders in the abdominal CT image, semi-automated segmentation methods like Active contours and graph cut are analyzed in the study.

Active contours are popularly known as snake method is used in medical segmentation to draw an outline of an object and thus help in segmenting the region of interest. The active contour takes some initial points known as hinge points as input and these help the contour to traverse and keeps moving until convergence is met[17]. The energy of the active contour is represented as

$$E\big(r(s)\big) = \int_s E_{internal} + E_{external} \qquad (1)$$

where *r(s)* represents the discrete set of points. $E_{internal}$ is determined by the properties of the contour such as elasticity, stiffness while $E_{external}$ is determined by image properties such as intensity, contrast and brightness.

The contour starts moving to the neighborhood for a better location determined by the lowest energy and iterates until all points in the contour move to a location of minimum energy. Active contours have two fundamental properties based on the force that drive the contour: similarity and discontinuity. Based on these two properties, region based active contour and edge based active contour algorithms are developed [14, 19-21]. Region based active contours use global information such as intensity, texture from the image for drawing and terminating of the contours at the edges. Chan Vese is one of the popular region based models. Chan Vese model is formulated by minimization of the following energy function and for a given Image I in domain Ω is represented as

$$E^{CV} = \lambda_1 \int_{inside(c)} |I(x) - C_1|^2 dx + \lambda_2 \int_{outside(c)} |I(x) - C_2|^2 dy$$

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where $x \in \Omega$ (2)

C_1 and C_2 are two constants and define the corresponding mean intensities inside and outside of the contour.

In Edge based active contours, contours evolution is based on the intrinsic geometric measures of the selected image [15]. The geodesic formulation used in the curve evolution draws the deforming curve towards the boundary, thus helping the detection of boundaries of objects which have differences in their gradient.

In Graph Cuts segmentation [14], a graph is generated from the image pixels and is separated into two disjoint sections using selection criteria and these two disjoint sets represent the foreground and background. The graph is represented as G $=[V, E, W]$, where V denotes the set of nodes and E denotes the set of edges and W denotes the weight associated with each edge. A cut on the graph partitions V into two disjoint subsets X and Y such that

$$X \cup Y = V \text{ and } X \cap Y = \Phi \quad (3)$$

The min-cut formulation partitions graph, G into two disjoint sets so that the sum of the W associated with the edges is minimized.

$$C_{\min}(X, Y) = \sum_{u \epsilon X, v \epsilon B} W_{uv} \quad (4)$$

The weights associated with each edge can also be viewed as flow of capacity from source to sink and the maximum amount of flow is equal to the capacity of minimum cut, hence the method is called as max-flow / min-cut graph method.

7. KIDNEY SEGMENTATION SIMULATION AND ANALYSIS

Noise filtered and contrast enhanced images are considered for kidney segmentation. The three segmentation techniques discussed above are applied and the results from the segmentation techniques are measured with ground truth obtained from expert radiologist. Quality of segmentation is measured using Dice Coefficient, which is a measurement of similarity between the segmented result and the ground-truth and is defined as [12]

$$\text{Dice Coefficient} = 2 * TP / (2 * TP + FP + FN) \quad (5)$$

where, TP is true positive, FP is false positive, FN is false negative

Axial view CT scan images with clear visibility of kidneys are considered for segmentation. Both contrast images (taken after contrast agent is injected to patient) and non-contrast images are considered for the study. Contrast images collected from arterial phase provide better visibility of lesions. For images with kidney lesions, seed points both from the normal and lesion area are considered.

The three segmentation techniques are run on the test dataset of abdominal CT images obtained after noise removal and contrast enhancement. Figure (7-9)b shows segmentation results from region based active contour, Figure (7-9)c shows results of edge based active contour and Figure (7-9)d shows results of graph-cut. Dice coefficient is measured from each of the results and given in the table below.

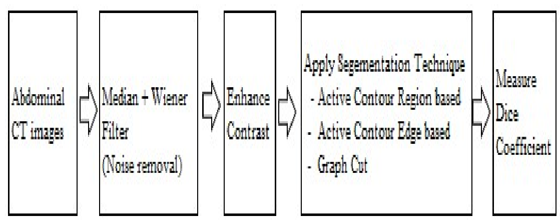

Figure:6: Simulation process of applying noise filters, segmentation techniques and measuring dice coefficient

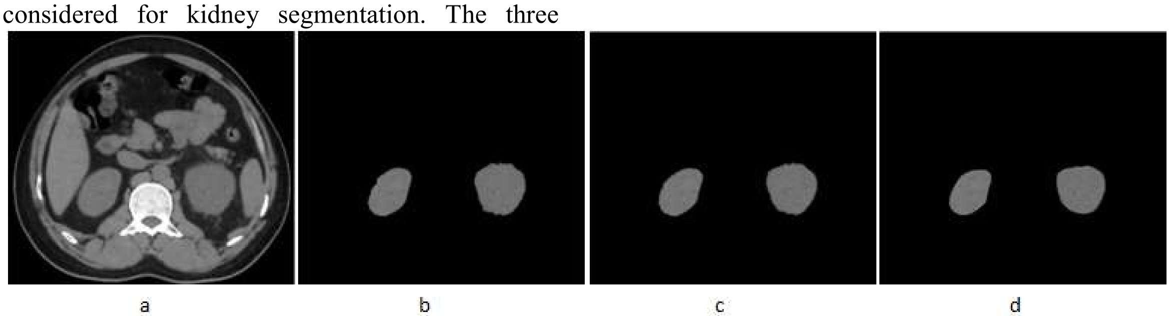

Figure:7: CT Image-1 a). Noise filtered and contrast enhanced CT test images, segmentation from b) Region based Active Contour c) Edge based Active Contour d) Graph Cut

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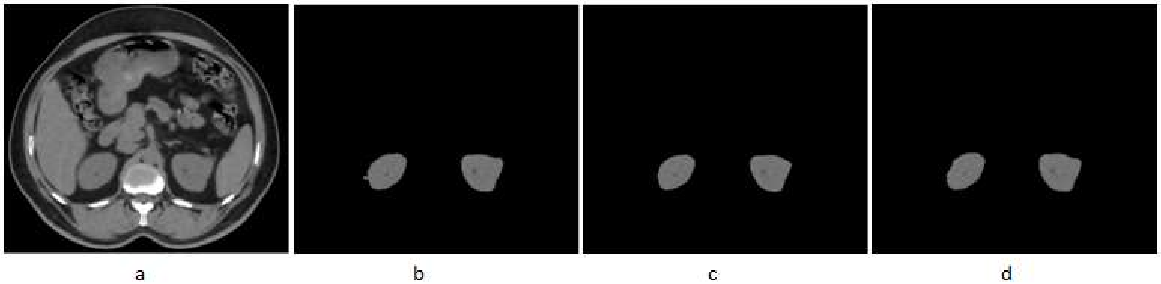

Figure:8: CT Image-2 a). Noise filtered and contrast enhanced CT test images, segmentation from b) Region based Active Contour c) Edge based Active Contour d) Graph Cut

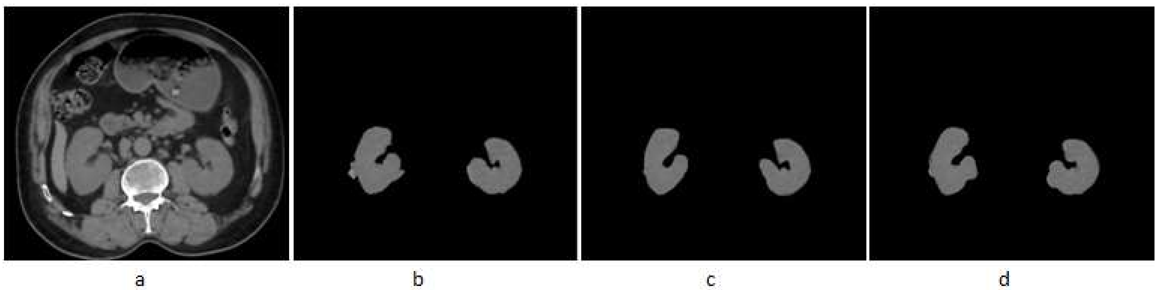

Figure:9: CT Image-3 a). Noise filtered and contrast enhanced CT test images, segmentation from b) Region based Active Contour c) Edge based Active Contour d) Graph Cut

Dice coefficient is measured from each of the results and given in the table below.

Table 4: Average Dice Coefficient for test dataset of CT images measured for different Segmentation Methods

Region based Active Contour	**Edge based Active Contour**	**Graph Cut**
0.9078	0.9531	0.9459

For kidney segmentation, all the three segmentation techniques are able to segment the kidney from the CT image. From the segmentation results, it is observed that region based active contour method sometimes crossed the kidney boundary covering neighbouring tissues as well. Edge based active contour and Graph Cut methods produced better results than region based from the sample test data. Also it is observed that the selection of initial points and number of iterations influenced the segmentation results.

8. CONCLUSION

In this paper, pre-processing of CT images is done for kidney lesion detection. As CT images have inherent noise, it is important to remove the noise for better segmentation results. Various noise removal filters are applied on CT images with Salt and pepper noise, Gaussian noise and speckle noise. From the simulation results, it is observed that Median filter works best for images with salt and pepper noise. Combination filter (Median followed by Wiener filter) also yield good results and close to the results of Median filter. For Gaussian and Speckle noise images, combination filter produces better results in noise removal. This is proved with image metrics showing lower MSE and higher PSNR and SSIM. Hence combination filter (Median followed by Wiener filter) is best suited as it produces good results for all kinds of noises present in the considered CT images.

For kidney segmentation, Region based, Edge based active contours and Graph Cut have been run on the test dataset of CT images. It is observed that region based active contour method sometimes crossed the kidney boundary covering neighbouring tissues as well. Edge based active contour and Graph Cut methods produced better results than region based from the sample test data. Also it is observed that the selection of initial points and number of iterations influenced the segmentation results. Taking the average of dice coefficients over a set of test data, it is observed that dice coefficient of Edge based active contour is produced better segmentation results than Graph Cut and region based active contours.

To conclude, for preprocessing of images for kidney lesion detection, combination filter (Median followed by Wiener filter) is an effective noise removal filter and Edge based active contour is an effective segmentation technique for kidney CT images.

9. FUTURE WORK

As the kidney could be successfully segmented from the abdominal CT image, further segmentation is required to identify the lesions present in the Kidney. Clustering algorithms can be explored to identify the lesions. Once the lesions are segmented, temporal and spatial resolution techniques can be used to further classify the lesion and detect the presence of cancer lesions in kidney.

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