Global Journal of Pure and Applied Mathematics (GJPAM) ISSN 0973-1768 Volume 12,Number 4 (2016)

Segmentation of abdominal organs using min cut/ max flow algorithm–An application of Graph theory

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***Abstract*—Medical image processing is the processing of medical images using computer aided algorithms for the analysis of anomalies. The segmentation of abdominal organs like kidney, liver from CT image is used as an effective and accurate indicator for the diagnosis in many clinical situations. The goal of this paper is to accurately segment the abdominal organs from low contrast CT images. The CT images are corrupted by gaussian noise and pre-processing was done by decision based median filter. The decision based median filter will not alter the non-noisy pixels unlike the conventional median filter. The segmentation was done by graph cut min cut /max flow algorithm. The Boykov - Kolmogorov (BK) augmenting path algorithm was used and it yields better results. The algorithms were developed in Matlab 2010 and tested on real time CT data sets. The results closely match with the manual delineation by the expert physician.**

Keywords*— *Segmentation; Graph cut; Computer Tomography;

I. INTRODUCTION

Medical imaging modalities like CT, MRI and PET have revolutionized the modern medicine. The medical images obtained from acquisition system are analysed for the diagnosis of anomalies like tumor and cyst. Medical image processing is the process of applying computerized algorithms for the analysis of anomalies. In image processing, segmentation is the process of extraction of desired region of interest in the image or it can also be stated as the separation of foreground object from the background. The segmentation algorithms can be broadly classified into three categories supervised, unsupervised and interactive [1] [2] [3]. The thresholding is the simplest technique, however it produce good results for high contrast objects with sharp edges and is sensitive to noise [4]. The watershed algorithm is sensitive to noise and it produce over segmentation in the case of objects with weak boundaries [5]. The active contour methods require crucial selection of the parameters and suffer from time complexity [6] [7]. In the case of neural network, training should be done properly to yield good results and parameters selection also affects the performance [8] [9]. The graph cut segmentation algorithm is an interactive segmentation approach and it is based on the graph theory in mathematics. The main objective of graph cut algorithm is to perform an optimum cut there by separating the object from the background [10] [11]. The graph cut segmentation algorithm yields better results than conventional segmentation algorithms like thresholding, region growing and watershed algorithm. Section 2 describes materials and methods comprising of acquisition protocol and algorithms used. Section 3 describes the results and discussion and finally conclusions are drawn in section 4.

II. MATERIALS AND METHODS

A. *Acquisition Protocol*

The CT images have been acquired on Optima CT machine. Both plain and contrast enhanced CT images were taken with 0.6mm slice thickness. The patient consent was obtained for publishing the images. The abdominal CT images of 9 data sets were used which comprises of three data sets of normal case, three data sets of malignant renal cell tumor (Renal Cell Carcinoma) and three data sets of malignant liver tumor (Hepatic Cellular Carcinoma). The preprocessing along with segmentation algorithms was applied on all the 9 data sets and the result of typical slices are depicted in the results and discussion. The ethics committee for biomedical activities of Mar Ephraem International Center for Medical Image processing and Metro Scans & Laboratory, Thiruvananthapuram approved the study of CT images of human subjects for research work.

B. *Preprocessing*

The median filter is a conventional spatial domain filter in which each pixel is replaced by the median of the gray values in the neighbourhood [12]. Though median filter is simple, it alters the non-noisy pixels also, hence decision based median filter is used in this paper which will not disturb the non-noisy pixels. It comprises of two stages, noise detection, noise filtering and is free from crucial parameter selection unlike progressive switched median filter**.**

C. *Introduction to Graph Theory in Image Segmentation*

A directed weighted graph G=(V,E) consist of a set of nodes V and a set of directed edges E that connect them. With respect to an image, the nodes represent the pixels. The cost function in graph cut algorithm comprises of terms corresponding to regional and boundary properties of the images. Let P represents pixels in a 2D image and 'N' represents neighbourhood system (8 or 24). The binary vector 'S' can be return as follows

$$S = (S1, S2 \ldots.Sp\ldots.SP) \qquad (1)$$

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This paper was presented by the first author in the National Conference on *Advances in Mathematics and its Applications to Science and Engineering* (AMASE-2016) conducted in Department of Mathematics, University College of Engineering-Pattukkottai, Thanjavur, Tamil Nadu, India, on 22nd January 2016.

Global Journal of Pure and Applied Mathematics (GJPAM) ISSN 0973-1768 Volume 12,Number 4 (2016)

The components of the binary vector 'S' can be either "object" or "background". The cost functions E(S) in terms of regional and boundary properties can be written as follows

$$E(S) = \lambda R(S) + B(S) \tag{2}$$

$$R(S) = \sum_{p \varepsilon P} R_S(S_P) \tag{3}$$

$$B(S) = \sum_{\{p,q\}\varepsilon N} B_{\{P,Q\}} \delta(S_P, S_q) \tag{4}$$

$$\delta(S_p, S_q) = \begin{cases} 1 & ; \text{ if } S_p \neq S_q \\ 0 & ; \text{ otherwise} \end{cases} \tag{5}$$

The term R(S) specifies the regional properties and B(S) specifies the boundary properties of segmentation of image ‘S’. The term R(S) describes how many pixels belong to object and background. The component B $_{\{p, q\}}$ is large when pixels p and q are similar and is close to zero when the pixels are different. A simple 2D segmentation using graph cut is depicted in figure 1. The ‘O’ represents the seed point for the object and ‘B’ represents the seed point for the back ground.

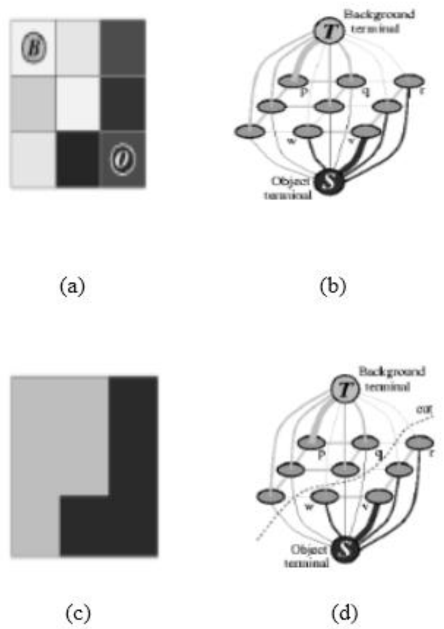

Figure 1: (a) Image with seed points, (b) Graph, (c) Segmentation result, (d) Graph cut

The n-links and t-links represent two types of edges in graph. The t-link connects pixels with terminals and the cost of t-link is defined by the data term R(S) The n-link connects pair of neighbouring pixels or voxels and cost of n link is defined by the interaction term B(S). The segmentation is done by minimizing the energy function by finding a minimum cut using maximum flow algorithm. An s/t cut 'C' on a graph with two terminals can be stated as the portioning of the nodes in the graph into two disjoint subsets 'S' and ‘T’, such that the source s is in 'S' and the sink t is in 'T'. The cost of a cut C={S, T} is defined as the sum of the cost of the boundary edges (p, q), Where p ε s and q ε T. The minimum cut problem on a graph is to find a cut that has the minimum cost among all cuts. The minimum s/t cut problem can be solved by BK maximum flow algorithm.

D. Boykov- Kolmogorov Algorithm

The basic principle of the Boykov-Kolmogorov (BK) algorithm is to maintain two search tree, one from the source and one from the sink. The trees are updated during the execution of the algorithm. Let 'S' and 'T' represents the two non-overlapping search trees with roots at the source 's' and the sink 't'.

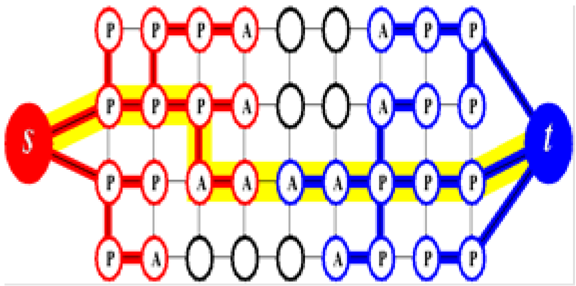

Figure 2: Principle of BK algorithm

All edges form each parent node to child node is non-saturated in 'S' tree, while in 'T' tree edges from child node to parent node are non-saturated. Free nodes are those nodes which are not in 'S' and 'T'. The nodes in search tree 'S' and 'T' can be classified into two types active or passive. The nodes that depicts the outer border in each tree are called active nodes while the internal nodes are called passive nodes. The search tree 'S' and 'T' can grow from active nodes by acquiring new children from a set of free nodes, while the passive nodes cannot grow since it is completely blocked by other nodes from the same trees. When an active node in one of the trees sense a neighbouring node that belong to the other tree, an augmenting path is created. The three stages in BK algorithm are growth stage, augmentation stage and adoption stage. The search trees ‘S’ and ‘T’ are depicted as red and blue coloured nodes and the free nodes are depicted in black colour. At the end of growth stage, a path (yellow line) is created from the source‘s’ to the sink ‘t’ and the active and passive nodes are represented by ‘A’ and ‘P’.

1) Growth stage: In this stage, the search trees 'S’ and ‘T’ expand through the active nodes. For each active node, the free nodes which are linked through non-saturated edges are searched. The newly acquired nodes will be the active nodes of the corresponding search tree. The active node will become passive node when all the free nodes are explored. The termination of growth stage occurs when an active node finds an adjacent active node that belongs to the other tree, there by an augmenting path from ‘S’ and ‘T’ was found.

2) Augmentation Stage: In this stage augmentation of the path determined at the growth stage takes place. Since the objective is maximum possible flow through the augmenting path, some edges in the path become saturated and the

Global Journal of Pure and Applied Mathematics (GJPAM) ISSN 0973-1768 Volume 12,Number 4 (2016)

saturated nodes are called orphans. The augmentation stage splits the search trees ‘S’ and ‘T’ into forest.

3) Adoption stage **:** In this stage, restoring of single tree takes place and for each orphan generated in the previous stage, the BK algorithm tries to find a new valid parent. If no valid parent is found, the orphan node and its child node become free. The tree rooted in that corresponding orphan is discarded. This stage terminates when all the orphan nodes are connected to a near parent or they are free. Once the adoption stage is completed, the BK algorithm returns to the growth state. The BK algorithm terminates when the search trees ‘S’ and ‘T’ cannot grow and the trees are separated by saturated edges that implies maximum flow is achieved.

III. RESULTS AND DISCUSSION

The segmentation algorithm was evaluated on 9 real time CT data sets. Prior to segmentation, the pre-processing was performed by decision based median filter. The algorithms were developed using Matlab 2010 and the BK algorithm code was written in C language. The mex file for the C code was incorporated in Matlab. The algorithms were executed in laptop with specifications of Intel Pentium(R) P6000 processor with 3GB RAM, 64bit windows 7 operating system.

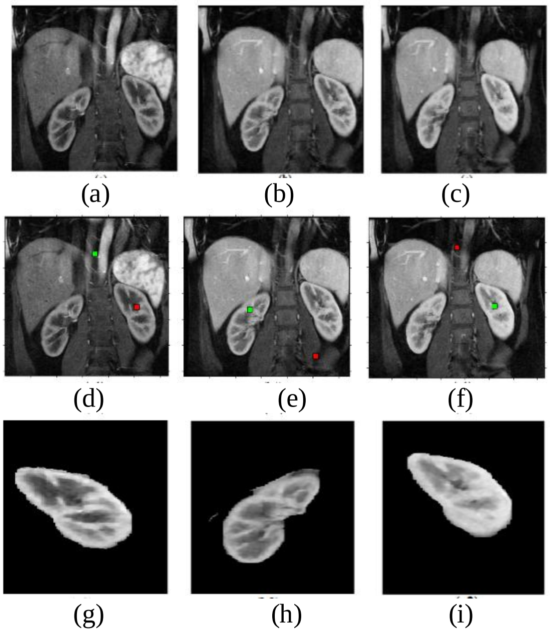

Figure 3: (a, b, c) Input CT image; (d, e, f) Seed point selection; (g, h, i) Kidney segmentation result;

Each data set comprises of 20 axial slice and 20 coronal slice images. The segmentation algorithm was evaluated on all data sets and result of typical slice in each data set is depicted here. The first row of figure 3 depicts the pre-processed input CT images. The second row in figure 3 depicts the seed point selection. The third row in figure 3 depicts the kidney segmentation result without any anomalies. Similarly the figure 4 depicts the kidney tumor segmentation result and figure 6 depicts the liver tumor segmentation result.

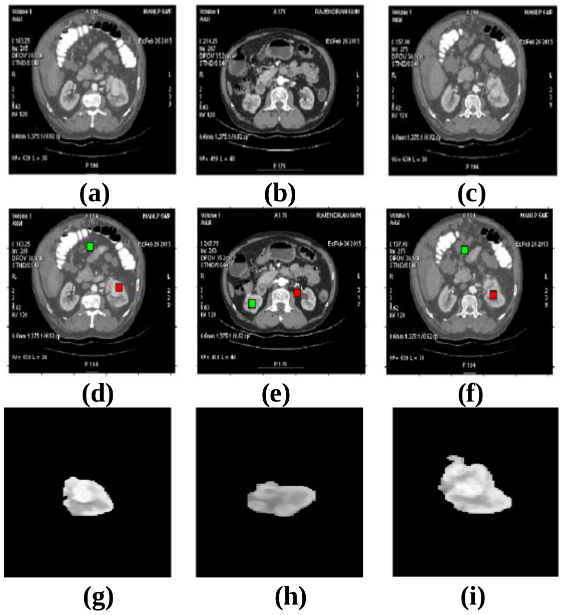

Figure 4: (a, b, c) Input CT image; (d, e, f) Seed point selection; (g, h, i) Kidney tumor Segmentation result;

The performance of graph cut segmentation algorithm was evaluated in terms of dice coefficient. It is a measure to indicate the percentage of spatial overlap between the segmented image and ground truth image. The dice coefficient is given by the equation.

$$D = \frac{2(S \cap G)}{(S \cap G + S \cup G)} \tag{6}$$

Where S and G are the segmented image and ground truth image.

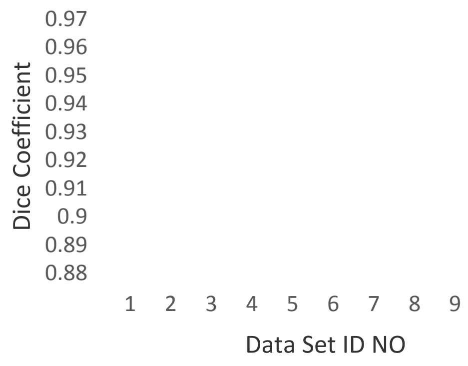

Figure 5: DC plot for data sets

The ground truth image was obtained by the careful delineation of ROI by expert radiologist. The dice coeficient value is 1 for perfect segmentation and the segmentation algorithm result is acceptable if DC $\geq$ 0.9 From the DC plot in figure 5, it is clear that the average value of dice coefficient is 0.94 and hence the graph cut algorithm yields optimum result.

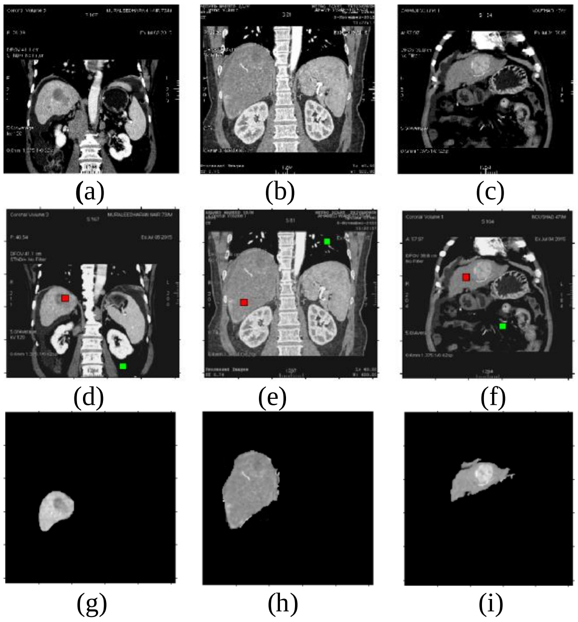

Figure 6: (a, b, c) Input CT image; (d, e, f) Seed point selection; (g, h, i) Liver tumor Segmentation result;

The graph cut segmentation algorithm thus yields good segmentation result for the extraction of abdominal organs in CT images, which was evaluated qualitatively by the radiologist and quantitatively by the performance metric.

IV. CONCLUSION

`In this paper the Min Cut /Max Flow graph cut algorithm is employed for the segmentation of abdominal organs in CT images. The pre-processing of input CT images was performed by decision based median filter. The DC value computed for all the data sets are greater than 0.9 that indicates the efficiency of the graph cut algorithm. The seed point selection is done manually in this paper and it involves human intervention. In future the seed point selection can be made automatic by incorporating neural network in the graph cut algorithm.

ACKNOWLEDGMENT

We thank Dr Sebastian Varghese (Consultant Radiologist, Metro Scans & Laboratory, Trivandrum) for providing the medical CT images, Anchalo Bensiger. S.M (ME: CSE, Mar Ephraem College of Engineering and Technology) and Ajay Kumar H (Department of ECE, Mar Ephraem College of Engineering and Technology for supporting us in the preparation of manuscript.

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