การทำความสะอาดลำไส้ใหญ่แบบดิจิทัลอัตโนมัติในภาพซีทีสแกน

นาย ไกรศร ชุณหพงษ์พิพัฒน์

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AUTOMATIC DIGITAL COLON CLEANSING IN CT SCAN IMAGES

Mr. Krisorn Chunhapongpipat

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By	Mr.Krisorn Chunhapongpipat
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..... Dean of the Faculty of Science

(Professor Supot Hannongbua, Dr.rer.nat)

THESIS COMMITTEE

..... Chairman

(Professor Chidchanok Lursinsup,Ph.D.)

..... Thesis Advisor

(Assistant Professor Rajalida Lipikorn,Ph.D.)

..... Examiner

(Assistant Professor Nagul Cooharojananone,Ph.D.)

..... External Examiner

(Associate Professor Praiboon Pantaragphong)

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ในประเทศไทยโรคมะเร็งเป็นหนึ่งในโรคที่สำคัญทางการแพทย์เพราะว่าประชากรไทยเสียชีวิตจากมะเร็งมากกว่าการเสียชีวิตสาเหตุหลักจากโรคอื่นๆและมีแนวโน้มเพิ่มขึ้นทุกปี โรคมะเร็งสามารถพบในอวัยวะต่างๆและหนึ่งในนั้นคือโรคมะเร็งลำไส้ใหญ่ซึ่งเป็นหนึ่งในโรคที่มีการตายมากที่สุด อย่างไรก็ตามชีวิตของประชาชนสามารถช่วยเหลือได้ถ้ามะเร็งสามารถถูกพบในระยะเริ่มต้นของมะเร็ง ระบบการจำลองลำไส้ใหญ่(Virtual Colonoscopy) ใช้ภาพถ่ายซีทีสแกนจากช่วงท้องถึงทวารหนักซึ่งเป็นเทคนิคที่ใช้ช่วยหมอวินิจฉัยลำไส้ใหญ่เพื่อหาหรือตรวจค้นก้อนเนื้อภายในลำไส้ ระบบการจำลองลำไส้ใหญ่ประกอบด้วยการเตรียมคนไข้ การทำความสะอาดลำไส้ใหญ่แบบดิจิทัลอัตโนมัติในภาพซีทีสแกน การสร้างโครงสร้าง สามมิติของลำไส้ใหญ่ ระบบการจำลองลำไส้ใหญ่สร้างมุมมองแบบ สามมิติภายในลำไส้ใหญ่ซึ่งสามารถทำให้แพทย์วินิจฉัยง่ายขึ้นและเดินทางตามเส้นผ่านศูนย์กลางภายในลำไส้ใหญ่เพื่อวัดระยะของก้อนเนื้อที่สงสัยจากรูทวารหนักและทำการบันทึก ถ้าเป็นก้อนเนื้อก่อนจะเป็นมะเร็งหรือละเว้นถ้าไม่ใช่ ผู้ป่วยจะรู้สึกถูกรุกรานและเจ็บปวดน้อยกว่าการสอดกล้องสำหรับส่องลำไส้ใหญ่ผ่านทางทวารหนัก

การทำความสะอาดลำไส้ใหญ่(Electronic colon cleansing)ในวิทยานิพนธ์เล่มนี้เป็นทางเลือกหนึ่งซึ่งสามารถกำจัดกากอาหารภายในลำไส้ใหญ่ที่อยู่ในภาพซีทีสแกนระหว่างการตรวจหามะเร็งลำไส้ใหญ่ในระบบการจำลองลำไส้ใหญ่หลังจากขยายเส้นผ่าศูนย์กลางของลำไส้ใหญ่ด้วยก๊าซคาร์บอนไดออกไซด์ วิทยานิพนธ์เล่มนี้เสนอวิธีใหม่สำหรับการทำความสะอาดลำไส้ใหญ่แบบดิจิทัลอัตโนมัติในภาพซีทีสแกนโดยใช้เกรเดียนแมคนิจุดและการวัดความเหมือนเพื่อตรวจหาและกำจัดกากอาหารจากภาพซีทีสแกนในลำไส้ใหญ่ซึ่งเป็นวิธีหนึ่งในระบบการจำลองลำไส้ใหญ่.

ภาควิชา คณิตศาสตร์ ลายมือชื่อนิสิต ไกรศร ชุณหพงษ์พิพัฒน์

สาขาวิชา วิทยาการคอมพิวเตอร์และเทคโนโลยีสารสนเทศ ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก รัชลิดา ลิปิกรณ์

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KRISORN CHUNHAPONGPIPAT : AUTOMATIC DIGITAL COLON CLEANSING IN CT SCAN IMAGES. THESIS ADVISOR : ASSISTANT PROFESSOR RAJALIDA LIPIKORN, 41 pp.

In Thailand, cancer is one of the most important leading causes of fidelity sickness in Thai people have died from cancer more and more and the death rate tends to increase every year. Cancer can be found in several organs and among them, colon cancer is one of the most deadly diseases. However, people's lives can be saved if cancers can be detected at an early stage. The system called Virtual Colonoscopy(VC) which requires a patient to take CT scan images from abdominal to anus, is a technique used to help doctor diagnose colon to find or detect polyps inside the colon. Virtual colonoscopy consists of patient preparation, electronic colon cleansing, 3D reconstruction of colon. Virtual colonoscopy gives 3D view inside the colon that enables a doctor to diagnose more easily and navigate inside the colon along the center line to measure the distance from the anus to a suspicious volume and mark it as polyp(before becoming tumor) or discard it. The patient will feel less invasive and less painful from passing the colonoscopy optical camera through their anus and colon. Electronic colon cleansing(ECC) presented in this thesis is an alternative method that can be used to remove remaining tagged fecal material(stools) from abdominal CT-scan image during colon cancer screening in virtual colonoscopy(VC) after inflating CO_2 to extend the colon diameter and to take CT scan images. This thesis presents a new method for automatic electronic colon cleansing using gradient magnitude and similarity measure to detect and remove tagged material from colon in CTC images which is a method in Virtual colonoscopy system.

Department : Mathematics Student's Signature Krisorn Chunhapongpipat
Field of Study : Computer Science and Information Technology Advisor's Signature Rajalida Lipikorn
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CHAPTER I

INTRODUCTION

1.1 Background and Motivation

People could die from many diseases and one of deadly diseases is cancer that kills many people in many countries around the world. There are several kinds of cancers, they depend on the location of cancer in the body and several treatment are used to cure the patients depend on the kind of cancer and individual patient. One kind of cancers that is often found among many cancers is cancer in colon or colorectal cancer. There is statistical that colorectal cancer usually can be found in old population. The colorectal cancer population in Thailand is reported to be increased in every year. For elderly who have colorectal cancer have to suffer from digest and evacuation problem. There is possibility to be cure by inspecting early in range of risk age.

The progress from polyp to tumor depends on what kind of cancer and ups to lifestyle and heredity of patient. There are differences of symptoms to indicate the stage of cancer after patient checked up. The suspicious tissue is inspected for stage of cancer or the development of its. The polyp is the beginning stage of cancer which can be cured. The treatment for each stage is different, depends on individual stage and patient. Colorectal cancer focuses on detecting cancer in early stage to cure it by specific way.

Colorectal cancer can happen in colon, rectum, or appendix. The beginning stage of cancer, polyp, have variety shapes. It is detected by its shape in possible area inside colon from doctor decision. The inspection of suspect tissue inside colon needs patients to prepare themselves before passing the optical camera through their anus and cutting suspect tissue to test. The procedure seems to be invasive, inconvenience, and uncomfortable for patient for couple days.

Virtual Colonoscopy system has been designed and developed for these problems. This system needs computed tomography images, CT-scan images, to create the virtual colonoscopy or 3D-view of colon structure to diagnose or analyze the shapes in colon structure. The patient preparation requires patient to take only low residual for a couple days and then take tagged solution(barium) for enhancing the intensity of the residual or fecal inside colon, normally the residual is liquid(water from patient preparation). After this, patients are inflated CO_2 into colon via anus for extending the diameter of colon. Patients take abdominal CT-scan images and doctor can diagnose from the extended colon structure. The tagged solution enables doctor distinguishes between the residual or fecal inside colon and tissue outside colon easier. The doctor can have vision for air, residual or tagged material, and tissue but it is still not automate tool to help doctor to find and diagnose the suspicious tissue by their shapes. Virtual Colonoscopy system makes doctor's job a lot easier to find and diagnose the suspicious tissue by using electronic colon cleansing technique, 3D reconstruction from CT-scan image method, and navigation along the central line of colon to measure the distance from anus to the suspicious tissues. The successful of this system is convenience, comfortable for both doctor and patient, and also less invasive for patient and is able to specify the location of the suspicious tissues automatically.

This thesis proposes method for electronic colon cleansing which is used in Virtual colonoscopy to remove the tagged material or residual inside colon from abdominal CT-scam images. The tagged material is removed for 3D-reconstruction of colon structure to merge the volume of tagged material and air together to obtain the real structure inside colon because the structure of colon needs to be reconstructed from air inside colon and volume of tagged material inside colon. Another benefit is doctor can do the patient screening a lot easier after there is no tagged material inside colon to confirm result from Virtual colonoscopy. Sometimes the suspicious tissue could be missed identify from Virtual colonoscopy or doctor then the confirmation is needed also. By the way, this is the main important method for other methods in Virtual colonoscopy to use this result produce precise output.

1.2 Research Objectives

This research is a part of virtual colonoscopy to improve electronic colon cleansing for CT scan images which have to correctly classify regions in colon into air, tagged material, bone and tissue. The fecal or tagged material inside colon is removed after classification. The result from removing tagged material inside colon yields the step edge between removed tagged material and tissue boundary and the artifact between air and tagged material remain in the image which is not desirable. The artifact between air and tagged material needs to be identified because its intensity is similar to the intensity of tissue. The surfaces of colon wall between removed tagged material and tissue boundary need to be reconstructed to make it smooth as the boundary between air and tissue.

1.3 Scope of work

The scope of this research is the abdominal CT-scan images which were taken from CT-scanner machine and patient who took the tagging solution to enhance the intensity of fecal or residual in abdominal CT-scan images. The patient was inflated the CO_2 into anus to extend the diameter of colon for clear structure of colon. The CT-scan image slides are processed individually. The proposed method focuses on the slides that contain colon only and will not identify the type of volume in abdominal CT-scan images data to distinguish between colons, stomach, and lung volume and leave identifying task be manual for user.

1.4 The definition of the research

Electronic colon cleansing is method for removing the tagged material inside colon in abdominal CT-scan images. Therefore, the 3D-reconstruction of colon structure can be improved by merging of the tagged material, which is volume inside colon, with air inside colon. The result from this method also enable view of inside colon in abdominal CT-scan image without tagged material and artifact layer between air and tagged material.

1.5 Expected Advantages

This research could be used in medical area as a tool for Virtual Colonoscopy system. The result is the 3D-reconstruction colon structure. Doctor will be able to remove the tagged material inside colon without artifact between tagged material and air boundary to analyze the shape of surface inside colon for making a decision and also use their opinion compare with Virtual colonoscopy system result. It will be easier for doctor's task. Patients who come for polyp screening do not have to be uncomfortable, inconvenience and invasive by passing the optical camera through the anus as in the past. The economic advantage is that the cost of medical software is very expensive so it wouldn't waste to invest to develop our own software which could have the same standard as commercial software or better and it is a lot cheaper.

1.6 Research Processes

In order to achieve the defined objective above, the following processes will be stated:

1. To find interesting research area then defines a problem and determines a technique suitable for such a problem.
2. To study concepts and methodologies by reviewing related literatures, requesting and getting data from Chulalongkorn Hospital.
3. To study the feasibility and available technology for this problem.
4. To pre-process data.
5. To define objective function and constraint in mathematical terms.
6. To realize a mathematic function in Matlab programming codes.
7. To extend scope and data for the experiment.

1.7 Literature Review

Several techniques for colon cleansing have been introduced in the literatures. For example, the electronic cleansing (EC) and digital bowel cleansing (DBC) techniques for digital tagged material removal using contrast agents [1] use prior knowledge about class intensity to initialize 6 classes by Markov random field for classification in order to remove bones and enhance material class. D.Chen *et al.* [2] extended their previous work to three dimensions with Markov random field and used local feature vector to classify the body voxel intensity. H.Yoshida *et al.* [3] pointed out the use of 3-D geometric features to reduce the false positives and the use of fuzzy clustering for segmentation which are aimed at polyp detection from defined shape. L. Li *et al.* [4] developed a statistical method of maximum a posterior probability (MAP) for an optimal classification by combining MAP-EM (Expectation Maximization) segmentation method with a hidden Markov random field (MRF). I. Serlie *et al.* [5] focused on mixture model to segment partial volume values at three-material transitions into volume percentages to recover material mixtures with sub-voxel accuracy to avoid the estimation of the contrast between enhanced material and fluid fraction from all voxels. M.E. Zalis *et al.* [6] used combination of morphological and spatial filtering technique to deal with artifact and to find volume of colon whose the main idea is about using edge threshold value for morphological with specific mask. Z. Wang *et al.* [7] improved their previous work for mixture segmentation by using expectation maximization as a parameter in maximizing a posteriori probability (MAP) solution and using morphological technique for artifact removal. I.W.O Serlie *et al.* [8] improved mixture model of three-material transitions to segment each component from image to deal with noise, global signal fluctuation, anisotropic scale , and non cubic voxels to make the method more precise for computer aided diagnosis and visualization of three dimensional colonic view. W.Cai *et al.*[9] introduced a method, called *structure-analysis cleansing*, to preserve the soft-tissue structures that submerged in or covered by tagged fecal materials using their local morphologic signature based on the characteristic of the Eigen values of a three-dimensional Hessian matrix. S. Ouadfel *et al.* [10] used swarmed based intelligent to automatically classify the pixels in an image into groups by the observation of real ants colony and based upon their collective foraging behavior.

CHAPTER II

Proposed Method

This chapter provides the methodology in this research.

2.1 Data

This project uses CT scan images data sets from Chulalongkorn hospital by collaboration between department of mathematics of Faculty of Science Chulalongkorn University and department of radiology, Faculty of Medicine in Chulalongkorn Hospital. The sample or data sets from two patients in two positions which are supine, patients lay on their back, and prone, patients lay on their stomach, were tested with our method. Each CT-scan image is a gray scale image with size 512X512 pixels. There are 512 images in each data set which also includes lung in our images.

2.2 Proposed Method

The proposed method consists of four steps: preprocessing, edge detection, region classification, and artifact removal.

2.2.1 Preprocessing:

The first step in colon cleansing is to prepare image data for electronic colon cleansing by converting image format from Dicom file to 8-bit gray-scale images. The range of the input is from 0 to 2000. The range 500 to 1500 is selected to convert into 256 gray-scale images as follow:

$$I_{out} = I_{in} \tag{2.1}$$

$$I_{out}(I_{in} < t_1) = t_1 \tag{2.2}$$

$$I_{out(}(I_{in} > t_2) = t_2 \tag{2.3}$$

$$I = \frac{I_{out} - t_1}{t_2 - t_1} \times 256 \tag{2.4}$$

Where I_{in} is dicom image. I_{out} is selected range image. t_1 is the lower bound threshold of selected range, in this case is 500. t_2 is the upper bound threshold of selected range, in this case is 1500. I is an 8-bit gray-scale image. This can be done by starting with initial I_{out} equals to I_{in} and then rounds up pixels that have value less than t_1 to t_1 and

rounds off pixels that have value more than t_2 to t_2. After this is normalization of I_{out} to [0, 1] range of intensity and then multiplies I_{out} with 256. To do this can reduce the computational time to compute just only 8-bit integer number value. Furthermore, we also reduce the computation time by reducing the number of pixels that are needed to be processed. This can be accomplished by first finding the boundary of a patient's body using Canny's edge detection, by using 0.1 as *high threshold* and 0.2 as *low threshold* for ignoring sensitive edge from small change of intensity, as show in Fig 2.2 and then removing the content outside the body that don't need by fill inside the boundary, the pixels that cannot be reached by filling in the background from the edge of the image is set as 1 and other is set as zero, as shown in Fig. 2.2. Next, the mask of the body is generated as shown in Fig. 2.3 and erosion on the mask is performed once in order to shrink the area of the body by using the structure element size 9×9 with 1's, B, as shown in Fig. 2.4. Where the erosion of the binary image , A , Fig. 2.3, by the structuring element B is defined by:

$$A \ominus B = \{z \in E | B_z \subseteq A\} \tag{2.5}$$

Which $E = \mathbb{Z}^2$ and $\mathbb{Z}^d$ is the integer grid for some dimension d ,$(d = 2)$, B is a 9×9 square, that is,

$$B = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix}$$

Then we perform logical AND operation between the original image and the mask (Figure 2.1) and the result image is shown in Fig. 2.5.

As we mentioned above about Canny's edge detection is be used in this preprocessing. Next section we will give more detail about Canny's edge detection which provide all notation and equation and algorithm in this method. We select this method because of its advantage over other popular edge detection method. For pro and con of other method can be reviewed in Appendix A.

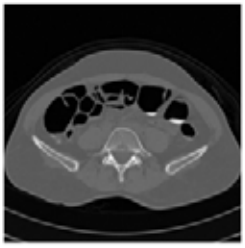

Figure 2.1: Original image with 256 gray-scale levels.

Figure 2.2: Canny's edge image.

Figure 2.3: Mask image which position of white pixel is used in this method.

Figure 2.4: Erosion of Figure 2.3.

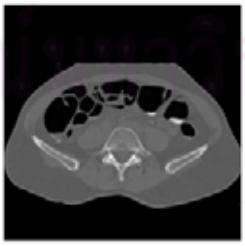

Figure 2.5: The pixels in the considered position.

2.2.2 Edge detection

This section explains the description of Canny's edge detection among many well-know edge detections with there are three advantages of this method to detect edge. Other well-know is explained in Appendix A. Three advantages of Canny's method are:

1. The detection criterion focuses on the fact that real edges should be detected and there should not be spurious responses.
2. The localization criterion copes with the distance between the real and detected position of edge to be minimal.
3. This third criterion deals with the problem of an edge corrupted by noise and works against non-smooth edge operators.

The detector is created in 2 dimensios which depends on position, orientation, and magnitude of the gradient of the image intensity function (strength of edge). This can be done by convolving an image with a symmetric 2D Gaussian filter then finding the gradient which is perpendicular to the edge direction to effective directional operator.

The 2D Gaussian function $G(x, y)$ is given by:

$$G(x, y) = \exp^{\frac{-\left(x^2+y^2\right)}{2\sigma^2}} \qquad (2.6)$$

To following the concept above, the image have to convolve with the derivative of 2D Gaussian function in direction of perpendicular to the edge which can be achieved by:

$$G_n = \frac{\partial G}{\partial n} = \vec{n}\nabla G \qquad (2.7)$$

Where G is 2D Gaussian function and n is perpendicular direction to edge which can be found by:

$$\vec{n} = \frac{\nabla\left(G * I\right)}{\left|\nabla(G * I)\right|} \qquad (2.8)$$

Where I is an image. The edge position is at the local maximum of the convolution between I and G_n in direction of $\vec{n}$ as follow:

$$\frac{\partial}{\partial \vec{n}} G_n * I = 0 \qquad (2.9)$$

substitute the Eq. (2.6) in Eq. (2.9) for G_n , then:

$$\frac{\partial^2}{\partial \vec{n}^2} G * I = 0 \qquad (2.10)$$

Eq. (2.10) shows how to find local maximum in the direction perpendicular to the edge which is called **non-maximal suppression** to suppress multiple responses in the neighborhood of single boundaries. The details of this method are as followed:

Non-maximal suppression of directional edge data algorithm

1. Quantize edge directions eight ways according to 8-connectivity
2. For each pixel with non-zero edge magnitude, inspect the two adjacent pixels indicated by the direction of its edge.
3. If the edge magnitude of either of these two exceeds that of the pixel under inspection, mark it for deletion.
4. When all pixels have been inspected, re-scan the image and erase to zero all edge data marked for deletion.

The strength of the edge is represented by:

$$\left|G_n * I\right| = \left|\nabla (G * I)\right| \qquad (2.11)$$

The streaking problem is caused by noise which edge detector responses it as spurious to the edge. There should be thresholds to distinguish between significant edge and streaking edge which should be suppressed. The strength can be above or below the thresholds. Two thresholds are used to determine significant edge ad streaking edge from each other, called **thresholding with hysteresis**. If the strength of edge is higher than a *high threshold*, the pixels with that strength are edge for specific σ in 2D Gaussian filter. The pixels that are connected with actual edges, more likely to be edge, will be edge if only its strength is over *lower threshold*. The low and high thresholds are estimated from signal-to-noise ratio.

Hysteresis threshold algorithm

1. Mark all edges with strength higher than a_1 as correct.
2. Scan all pixels with strength in the range $[a_0, a_1]$.
3. If such a pixel borders another already marked as an edge, then mark it too. 'Bordering' may be defined by 4- or 8- connectivity.
4. Repeat step 2 until stability.

Canny edge detector algorithm

1. Convolve an image I with a Gaussian of scale σ.

2. Estimate local edge normal directions $\vec{n}$ using Eq. (2.8) for each-pixel in the image.
3. Find the location of the edges using Eq. (2.10) which is **non-maximal suppression**.
4. Compute the strength of the edge using Eq. (2.11).
5. Threshold edges in the image with hysteresis to eliminate spurious responses.

There are two parameters which are high and low thresholds for hysteresis thresholding and standard deviation for image scaling. Thresholds are divided into two values; high threshold is used to detect strong edge and low threshold is used to detect weak edge. The threshold has range in $[0,1]$. The high threshold is set to 0.2 and low threshold is set to 0.1. The standard deviation is set to 0.5. These thresholds and standard deviation value depend on data.

Canny's edge detection is used to find edge for segmenting the area of the body from the CT-scam image as explained in section 2.2.1 and edge that we have got from Canny's edge algorithm is used to perform with logical AND operation to obtain only the edge inside the body as shown in Fig. 2.8. The edge inside the body will be used later for classification.

The main problem of any edge detection methods is the possibility of leak edge. All regions or classes cannot be classified by using only edge detection. They need the algorithm to help the problem from edge leaking to perform cluster of classes which are air, tissue, High density (bone or tagged material). For the objects in image that can be enclosed by edge detection can be used to identify the region inside the boundary by its intensity. The area inside enclosed boundary performs by using the fill holes method as in section 2.2.6. After we identify some objects or regions in image, there are some pixels that are not identified or classified yet so the similarity measure is used to apply as in section 2.2.11. The minor problem of any edge detection methods is about noise when it is used to work with CT-scan image because the protocol of CT-scanner machine that converts signal from many radiation axis's yield to CT-scan image result. Next section explains about how to remove noise from Canny's edge detection with specific parameter value that we choose.

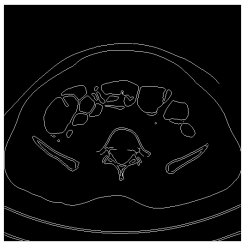

Figure 2.6: Canny's edge image.

Figure 2.7: Erosion of Figure 2.3.

Figure 2.8: The convolution of Figure 2.6 and Figure 2.7.

2.2.3 Salt Noise Removal

For edge image obtained from the previous step, we only need to define the boundary of objects in an image, thus there are noise that need to be removed. These noises are objects in an image that seem like edge but they are smaller, disconnected and typically removed by non-edge pixels (background). The pixels, that are edge, are labeled as 1's in image and the pixels that are not edge, are labeled as 0's. A pixel that is edge but surrounded by the pixels that are not edge, is removed. The 8-neighbor is used to find an edge pixel that is surrounded by the pixels which are not edge. Next, we explain a method that can help solve the problem of edge leaking when unconnected edges have a few pixels to connect to each other.

2.2.4 Interpolation

If there are only two edge pixels in a 3x3 mask, a pixel in the middle of the mask will be disconnected edge pixel. The boundary will not be closed, if there are disconnected edge pixels. After the disconnected pixel is found, the mask will be extended until finding other disconnected pixels. Each mask extension is (2*n+1)x(2*n+1), where n is 2 to 6 because the new pixels, which just come in the extended mask, may come from the other boundaries, thus the extended mask size is selected to avoid the accident on the boundary of other object when interpolation . The interpolate line between two disconnected pixels are drawn as Fig. 2.9.

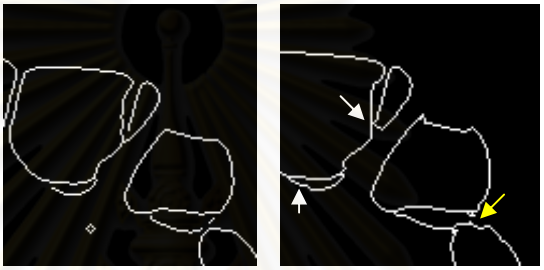

Figure 2.9: (Left) part of Canny's edge image and (Right) the interpolation in Canny's edge image by white arrow. Yellow arrow shows unexpected interpolation.

After we perform close boundary as much as possible next we fill in the close boundary to obtain the area for calculating the average the intensity pixels value in each close boundary.

2.2.5 Holes Filling

A hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image. The closed boundary is the line of edge in the image. The area is created by filling the holes that are surrounded by the edge line as shown in Fig. 2.10.

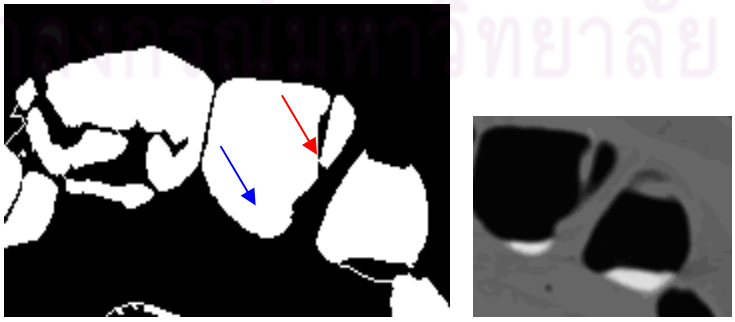

Figure 2.10: (Left) edge image which are filled in the closed boundary. (Right) image is a zoom in version of CT-scan image of left image.

Next section is about how to separate two regions that connect to each other.

2.2.6 Separation connected regions

The binary image is used to illustrate edge image as shown in Fig. 2.11 with yellow pointer. A closed boundary in edge image is filled inside by 1's as show in Fig. 2.11 in white area that blue pointer points. Edge line is the partition line between two regions but when the region is filled the partition line is gone because they are also represented by 1's in pixels that are in the partition line. The subtraction of two binary images which are filled edge image and edge image can separate two regions that are adjacent to each other as show in Fig. 2.11 by red pointer. Fig. 2.12 is pointed by red and blue pointer on the left shows the separated regions which is different from Fig. 2.10 which is also pointed by red and blue pointer.

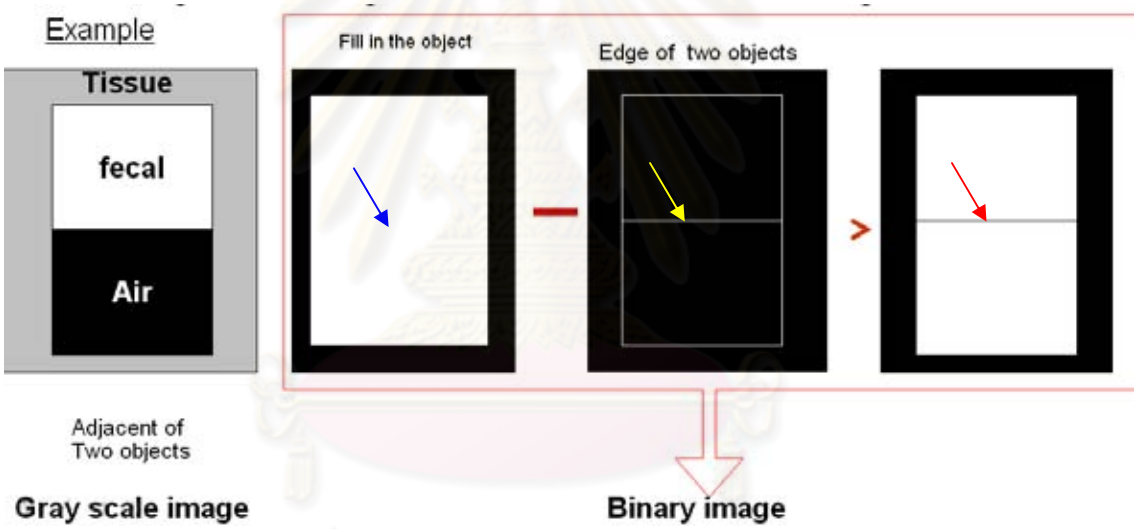

Figure 2.11: Separation of the connected different region types.

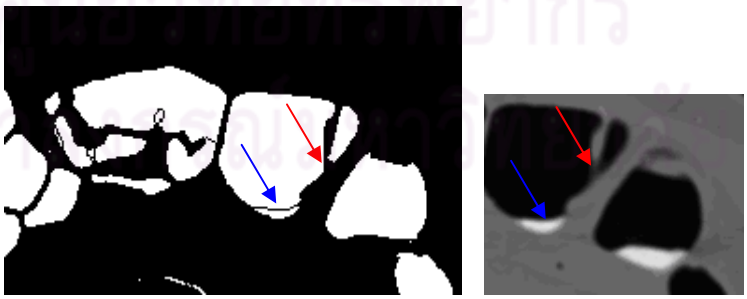

Figure 2.12: (Left) the result of subtraction of filled image and edge image. (Right) image is a zoom in version of CT-scan image of left image.

Next section will explain about classification method which is used to identify the regions that we have right now by using histogram and average of intensity of each region.

2.2.7 First Classifying: Region classification

The regions that are originated from closed boundary must be classified by its average intensity. The structure of closed regions inside body which are air and High density (fecal tagging material and bone) are classified by comparing with intensity of tissue. The intensity that is used to represent tissue is the intensity that was the highest frequency or mode in statistic when the pixels in the background outside the body are not considered. The intensity value with the highest frequency in the body pixels, is represented by ***max_frequency_Intensity***, (MFI), is used to classify each region as followed:

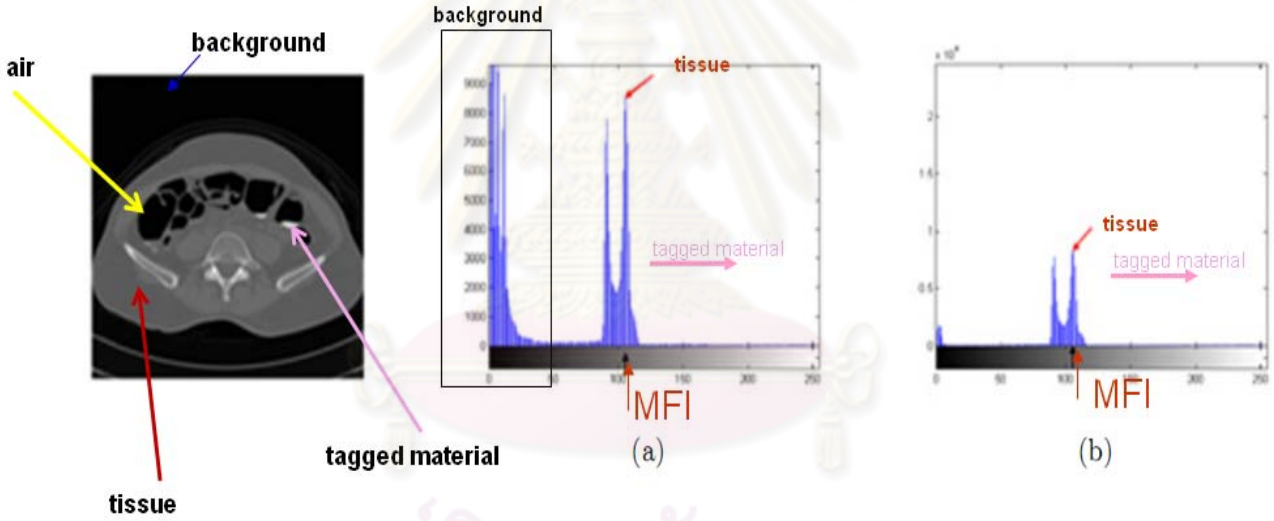

Figure 2.13: (Left) image shows each component in CT-scan image by different color of pointer. The middle image, (a), is histogram image with background pixels. (Right) image, (b), is histogram image without considering background pixels.

The left image of Fig. 2.13 shows each component with color arrows. The blue arrow points to the background. The yellow arrow points to the air region. The pink arrow points to fecal tagging material. The red arrow points to tissue region. The middle image, (a), shows the histogram of an abdominal CT-scan image. The background has the most pixel numbers in an abdominal CT-scan image. The right image, (b), shows the histogram of an abdominal CT-scan image without background pixels. This histogram

shows that when the background is not considered for histogram so the most number of pixels is tissue type. The MFI is used to be the partition between air region and high density region.

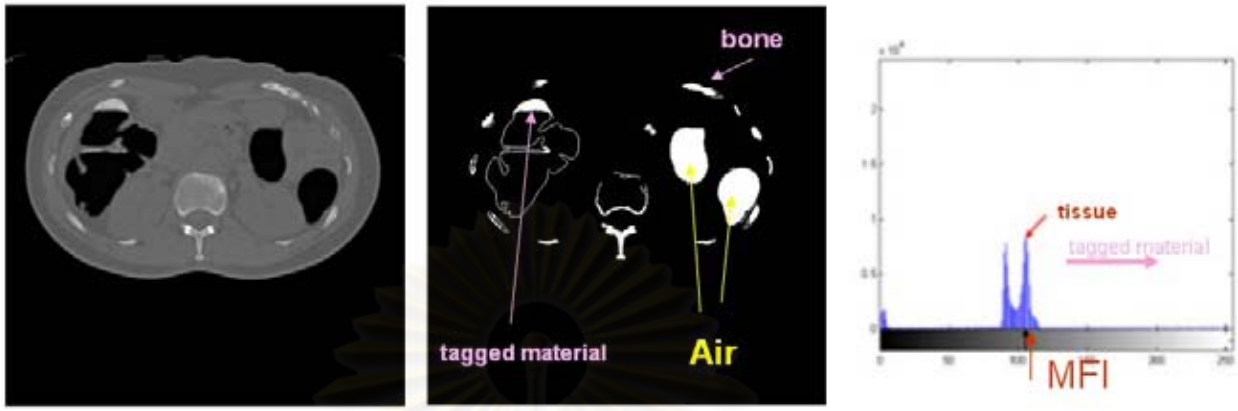

Figure 2.14: (Left) the original image. The middle shows the regions in close boundaries are labeled as different classes. (Right) image, (b), is histogram image without considering background pixels.

The regions that have average of their intensity less than MFI go to air class as shown in Fig. 2.14 in the middle. The regions that have average of their intensity more than MFI go to high density (fecal tagging material and bone) class as shown in Fig. 2.14 in the middle. The high density class consists of fecal tagging material regions and bone region in abdominal CT-scan image. Now we have already initialized two classes which are air class and high density class.

The problem from edge leaking yields to the classification of every pixel in abdominal CT-scan image are not covered. There are some pixels that are already classified and the rest of the pixels, which could be air and high density, need pixels that have been classified in order to compare the similarity with them. The air class is not interesting to classify because it is not the target class. The objective is to gain all pixels which should be in high density classes.

Next section explains about how to classify the rest of the pixels which should be air, tissue, and high density but pixels that belong to air class is not considered. The similarity classification is the classification between two classes which are high density class and tissue class. The result from the next section is all pixels that belong to high density class are classified and these pixels will be removed.

2.2.8 Second Classifying (Similarity function): Region classification

All pixels, as shown in Fig. 2.15 in the middle image, that have not been classified and should belong to one of two classes which are high density class or tissue class will be considered in this section. The MFI value is used to initial pixels in tissue class so every pixel that have intensity equal to MFI are in the tissue class. The rest pixels that have not been classified and higher than MFI are used to compare the similarity with the pixels that are classified as high density and tissue class that have just been initialed. One pixel in the rest pixels is used to compare the intensity to every pixel in both of two classes, tissue and high density class. One of two classes that is similar to this pixel the most will take this pixel as one of pixels in that class as in Fig. 2.16. The rest pixels will be compared with two classes and classified to one of two classes until there are no pixels left to be classified.

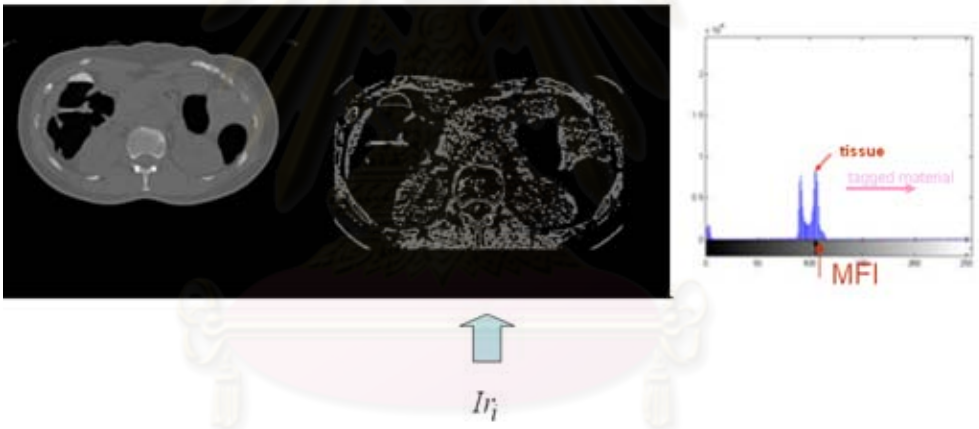

Figure 2.15: (Left) image is an abdominal CT-scan image. The middle show the rest pixels , Ir_i , that have not been classified and have the intensity higher than MFI. (Right) image is an histogram of the left image and shows the intensity value of MFI.

The similarity function is used only on the pixels with the intensity value higher than MFI to calculate the similarity between high density class and tissue class. The similarity function is shown as followed:

$$s_1 = \frac{1}{m} \times \sum_{j=1}^{m} \sqrt{(Ir_i - e_j)^2} \qquad (2.12)$$

$$s_2 = \frac{1}{n} \times \sum_{j=1}^{n} \sqrt{(Ir_i - t_j)^2} \qquad (2.13)$$

Where s_1 is the similarity of a pixel and pixels in the high density group, s_2 is the similarity of a pixel and pixels in the tissue group. Ir_i is the i^{th} of the pixels with the intensity value higher than MFI and are not in any group. m is the number of pixels in high density group. n is the number of pixels in the tissue group. e_j is the j^{th} of pixels in high density class, E, which are fecal tagging material and bone. t_j is the j^{th} of pixels in tissue class, T.

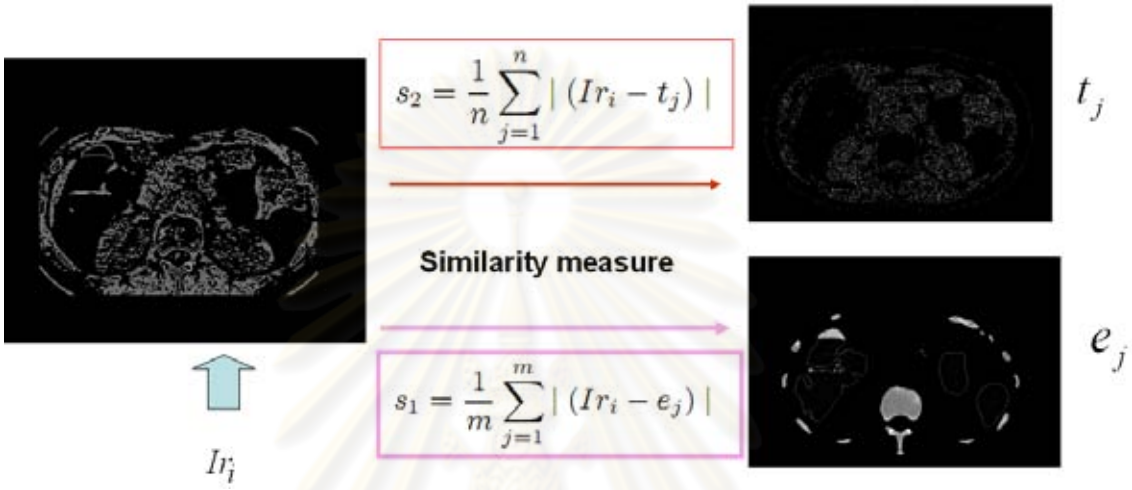

Figure 2.16: the process of similarity classification.

If $s_1 > s_2$, Ir_i will be added in the class of tissue and labeled as tissue pixel.

$$Ir_i \in T \mid s_1 > s_2 \qquad (2.14)$$

If $s_1 < s_2$, Ir_i will be added in the class of high density and labeled as high density pixel as in Fig. 2.17 in the left image.

$$Ir_i \in E \mid s_2 < s_1 \qquad (2.15)$$

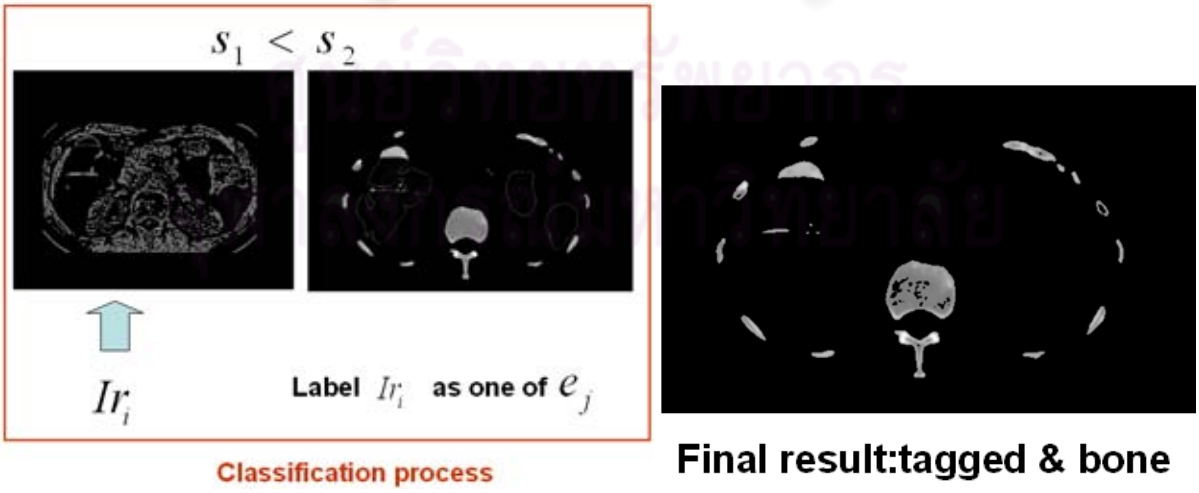

Figure 2.17: The left image shows the process when $s_1 < s_2$. The right is the final result.

This classification locates all the pixels that should belong to the class of high density, and then these pixels are removed from the CT-scan image.

The next section we will deal with the artifact problem. The artifact is the layer that has the intensity similar to tissue class but there is possibility that it is not tissue. The location of this kind of layer is in between air and fecal tagging material. It could be either artifact or real tissue. The character of artifact layer has high gradient magnitude value. The next section explains about gradient magnitude.

2.2.9 Magnitude of gradient

Gradient is used to measure the differences in x-and y-directions. The area of high rate of change of intensity (air-to-tagged material, air-to-tissue, tissue-to-tagged material) are in image. The gradient equation is as follow:

$$\nabla I = (\frac{\partial I}{\partial x}, \frac{\partial I}{\partial y}) \qquad (2.16)$$

Magnitude of gradient is used to find the rate of change of intensity in both axes which is:

$$|\nabla I(x, y)| = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2} \qquad (2.17)$$

The magnitude of gradient value is converted into gray-scale (0-1) as in Fig. 2.18. The visible value of magnitude of gray-scale gradient is higher than 0.1 because the pixels in magnitude of gray-scale gradient image are able to see when they are more than 0.1 as in Fig. 2.21. The structure of colon and bone gradient magnitude (Fig. 2.22) is extracted by convolution with the erosion of mask body (Fig. 2.20) like in section 2.2.1.

Classification the artifact layer and the real tissue layer needs to use the gradient magnitude by thresholding method and position of the patient in abdominal CT-scan image. Next section is about the definition of artifact layer and real tissue that are in between air and fecal tagging material. This yields better result when the result is the input of 3D-reconstruction because the artifact can be in the 3 dimensions structure when it is not removed which it is not desirable.

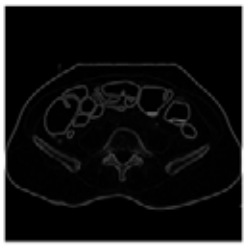

Figure 2.18: Gradient magnitude image.

Figure 2.19: Body position (white pixels)

Figure 2.20: Erosion of Figure 2.19.

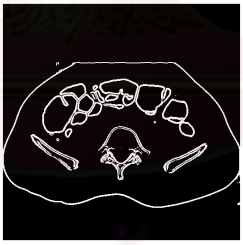

Figure 2.21: Position (white pixels) of gray-scale gradient intensity value above 0.1.

Figure 2.22: The convolution of Figure 2.11 and Figure 2.12.

2.2.10 AT vs. ATT Layer

AT and ATT are the layers that are between air and fecal tagging material which layer could be the artifact layer between air and fecal tagging material as Fig. 2.23 at red arrow, which is called AT, or could be the tissue layer between air and fecal tagging material as Fig. 2.23 at yellow arrow, which is called ATT.

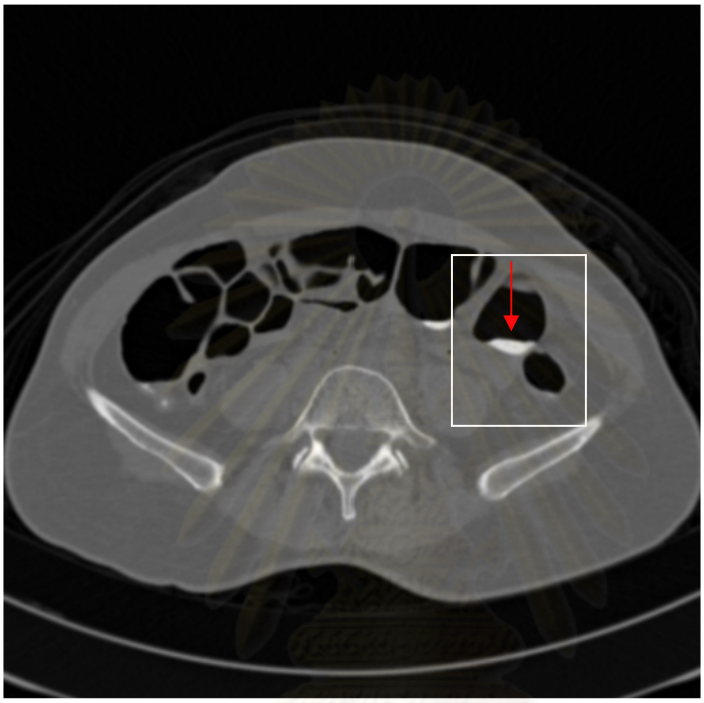

Figure 2.23: The red arrow points to AT layer. The yellow arrow points to ATT layer.

AT and ATT are distinguished by the values of their gradient magnitude and the positions of the layer between fecal tagging material and air region. The threshold of AT and ATT gradient magnitude comes from the mean of the gray-scale value of gradient magnitude–values above 0.1- plus three quarter of median of the gray-scale value of gradient –values above 0.1- as followed:

$$threshold\_mag = mean + \frac{3}{4}median \qquad (2.18)$$

The gray-scale value of gradient magnitude of AT layer is significantly higher than ATT layer as in Fig. 2.24, thus another threshold is needed to differentiate the AT layer from ATT layer. The threshold of AT layer is as followed:

$$threshold\_AT = \frac{4}{3}mean + median \qquad (2.19)$$

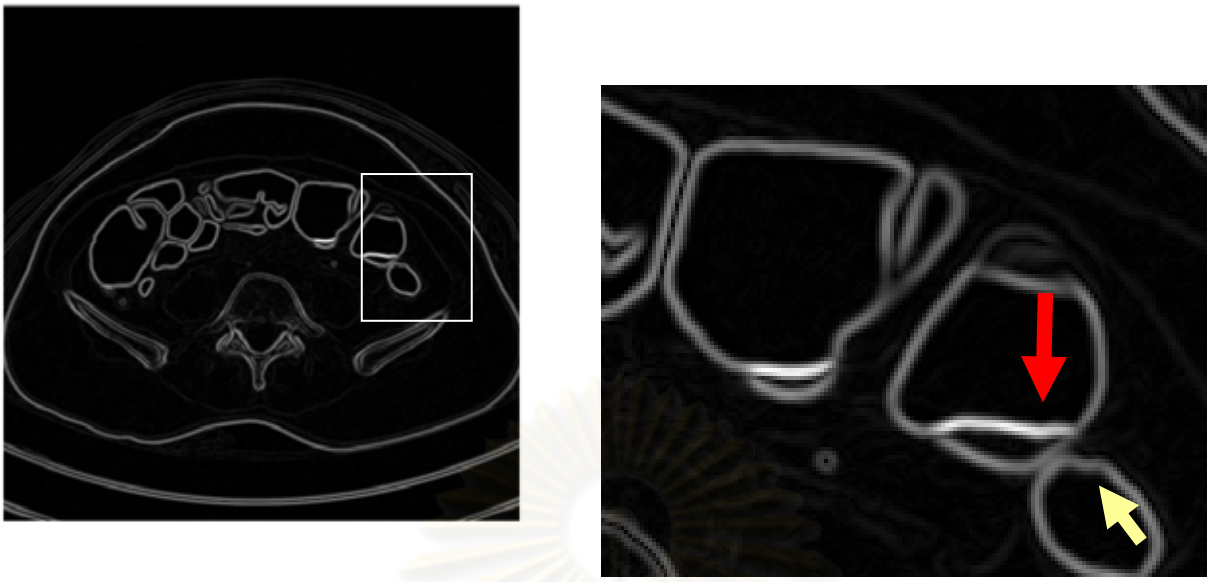

Figure 2.24: The red arrow points to gradient magnitude of AT layer. The yellow arrow points to gradient magnitude of ATT layer.

However, this gradient magnitude values are the area between air-tissue or tagged material-tissue so a 3x3 mask is used to remove the pixels that do not involve in air-tagged material layer by considering the intensity value of pixels along the threshold of AT gradient gray-scale value. The pixels in the mask with only the intensity value less than MFI minus standard deviation of the body pixel or with the only intensity value higher than MFI add standard deviation of the body pixel will be ignored. Because they are not the pixels between air and tagged material regions. The mask which contains the pixels with both intensity value less than MFI minus standard deviation and the intensity value more than MFI add standard deviation will be extended until it covers the gray-scale gradient pixels with the intensity value less than 0.1. The all pixels in mask are removed because they are AT layer.

The position of the layer between fecal tagging material and air region is used to consider the AT layer that has lower intensity than $threshold\_AT$ because sometimes tagging solution is not concentrated enough when it is mixed with water inside colon so fecal tagging material in abdominal CT-scan image has insufficient contrast. The tagged material region that has the highest number of pixels in the image and is surrounded with two different components (air and tissue) is used to be considered. The boundary between tagged material and air is able to define the layer whether should be

removed or not. If the tagged material is above the air, all the layers between the tagged material region and the air region, are on the air region, have to be removed. If the air is above the tagged material, all the layers between the air region and the tagged material region are on the tagged material have to be removed.

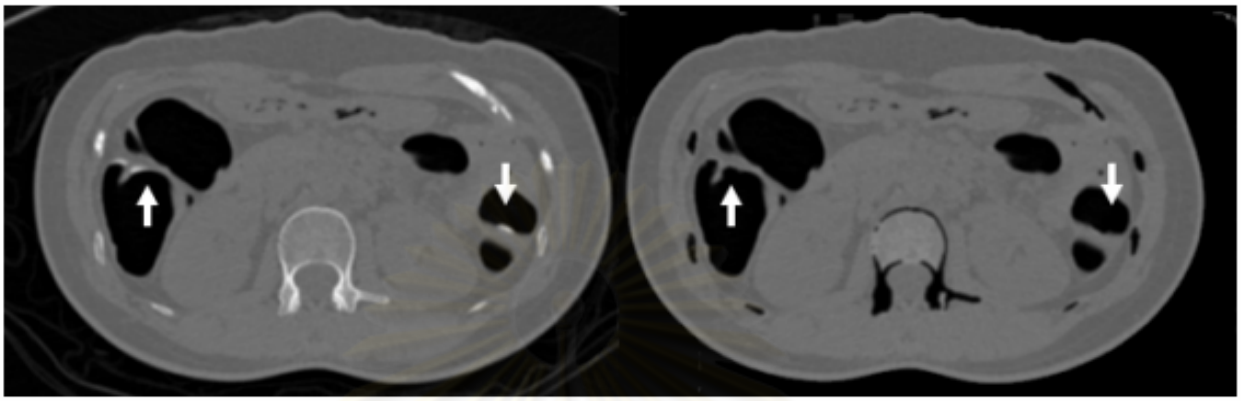

Figure 2.25: The result of removing the artifact.

The first benefit of the consideration of the gradient and the position of the layer between fecal tagging material and air region is to remove the AT layers with the gray-scale gradient magnitude lower than $threshold\_AT$ which also is better than to only consider the position of the attachment of tagged material and air region because the layer between these two components could be ATT layer and can lead to a mistake. The second benefit is a case that there is the fecal tagging material on the tissue layer and the fecal tagging material under the tissue layer. It is able to remove the AT layer in both cases of tagged material as shown in Fig. 2.25.

Next is the last section of the proposed method. The result from previous section is the classification and the fecal tagging material and artifact removal from abdominal CT-scan image. The removing the fecal tagging material is the detection of location of fecal tagging material and then change it to some intensity that is preferred. The intensity that is used is the intensity of air or zero because the objective needs to synthesis the boundary as air and tissue. The boundary from removing the fecal tagging material from abdominal CT-scan image is not so smooth. Next section we will give simple detail to synthesis the boundary between air and tissue from removing fecal tagging material.

2.2.11 Reconstruction

The abruptly changed edge happens after the pixels are set to zero. The reconstruction is a method of changing contrasted area to be shaded area as the real boundary between air and tissue. The Gaussian's blurring technique with standard deviation equals to 1 and a mask of size 7x7 size is used to blur the areas that have abruptly changed edges after that a 3x3 average filter is used to make it smoother as in Fig. 2.26-2.28.

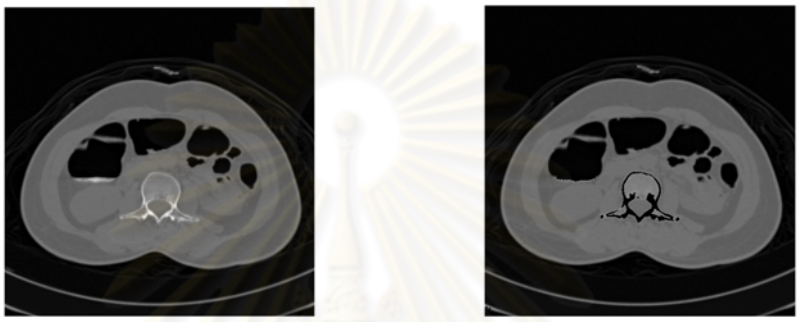

Figure 2.26: (Left) the abdominal CT-scan image.(Right) the abdominal CT-scan image from removing the fecal tagging material.

Figure 2.27: (Left) a zoomed version of Figure 2.26(Right). (Right) the abruptly changed edge which is zoomed version of Left.

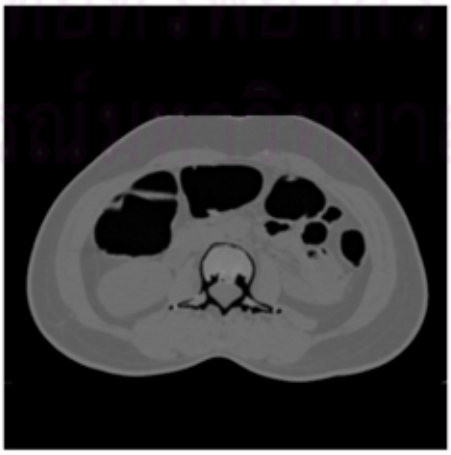

Figure 2.28: (Left) the result image. (Right) the shaded edge.

CHAPTER III

Result

3.1 Analysis result

The examples of successfully results are shown in Fig. 3.1-3.5. Fig. 3.1 shows the preservation of the layer that is between fecal tagging material and air as pointed red arrow and removing the artifact layers are between fecal tagging material and air as pointed by white arrows. Fig. 3.2 shows how well the electronic colon cleansing proposed method can perform as white arrows point but some fecal tagging material that the contrast is not very clear could yield inefficient colon cleansing because every pixel in CT-scan image have influence to each other from reflection of each particle when it takes CT-scan image from the radiation as pointed by yellow arrows. Another reason for inefficient colon cleansing in proposed method involves with the regions that can perform from edge detection in initialization of regions for classification. If it can cover pixels that are very sensitive that could be either tissue or fecal tagging material, the classification for pixels identification will be better. This is why some fecal tagging material in Fig. 3.6 pointed by red arrow and Fig. 3.2 pointed by yellow arrow are treated differently. The reason is because they are in different abdominal CT-scan image and the abdominal CT-scan image of Fig. 3.6 can perform the classification that covers the pixels in red arrow but the abdominal CT-scan image of Fig. 3.2 cannot perform in the same way because the individual slice CT-scan image have histogram which yield the classification by similarity clustering as shown also in Fig. 3.7-3.9 pointed by yellow arrows.

Sometimes the classification is not correct when it classifies the pixels that could be in either tissue or high density class. The yellow arrow in Fig. 3.10 points the area that the classification method classifies pixels in that area as high density but it should classify only small part in that branch to be high density only.

Sometimes the classification is correct when it classifies the pixels that could be in tissue or high density class. The red arrow in Fig. 3.11 points to the area that

the classification method classifies pixels in that area as high density and it classifies the small part in that branch to be high density which is correct.

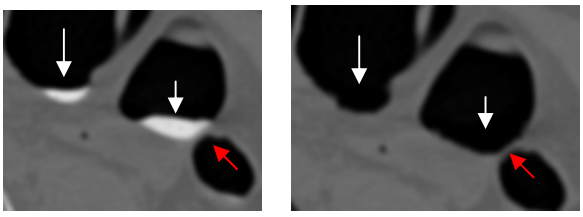

Figure 3.1: Left is the area of tagged or enhance material region. Right is the removed tagged area and red arrow points to ATT layer.

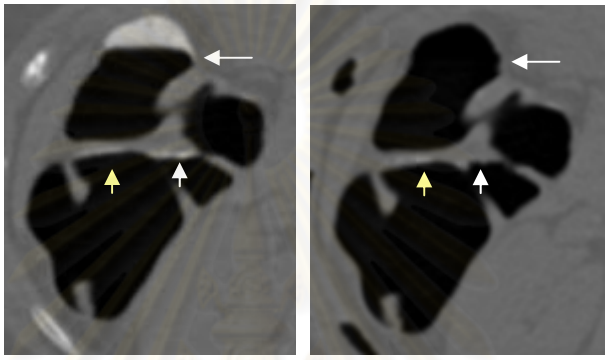

Figure 3.2: Left is the tagged area of prone patient pose. Right is the result.

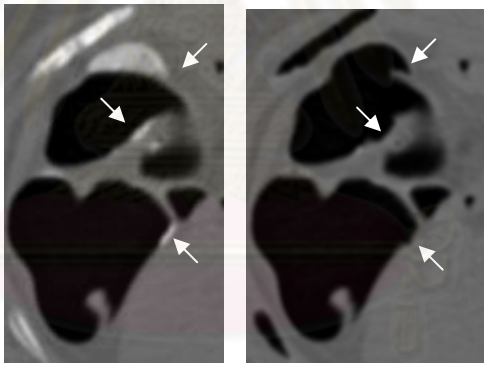

Figure 3.3: Left is the tagged area of prone patient pose. Right is the result.

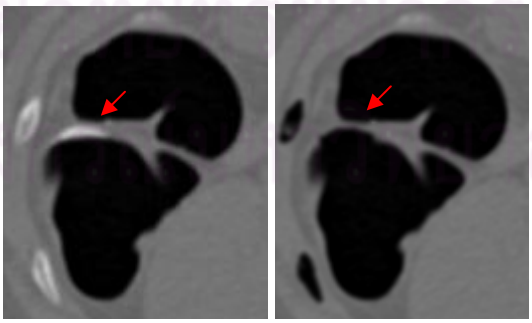

Figure 3.4: Left is the tagged area of prone patient pose. Right is the removed tagged area. Red arrow shows ATT layer.

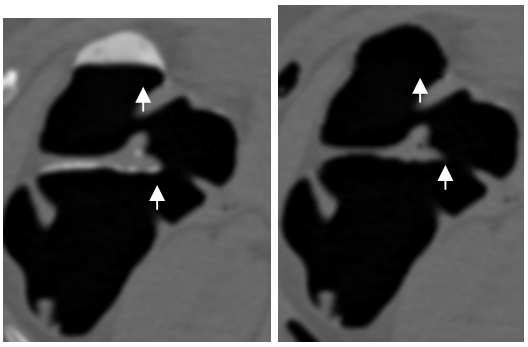

Figure 3.5: Left is the tagged area (white arrow) of prone patient pose. Right is the removed tagged material area (white arrow).

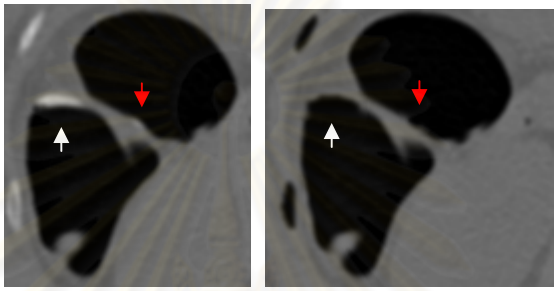

Figure 3.6: Left is the case that has both tagged material on the tissue (white arrow) and under the tissue (red arrow). Right is the removed tagged material version of Left.

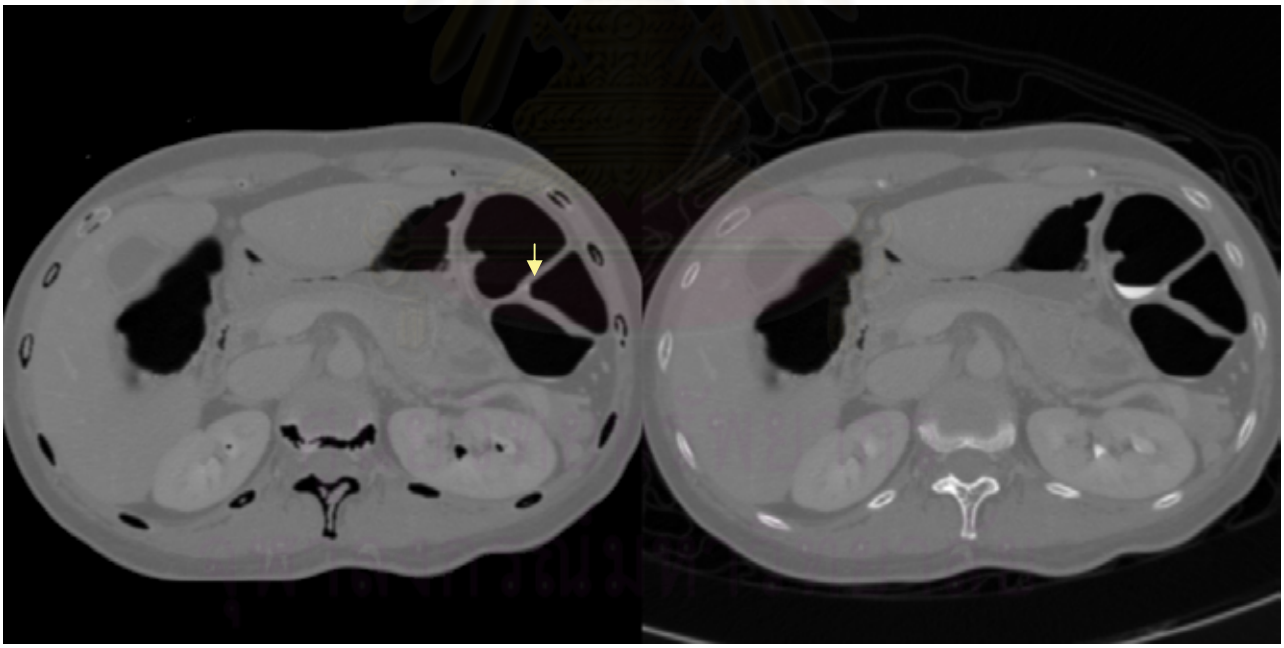

Figure 3.7: Left image is the result from proposed method. Right is the original abdominal CT-scan image.

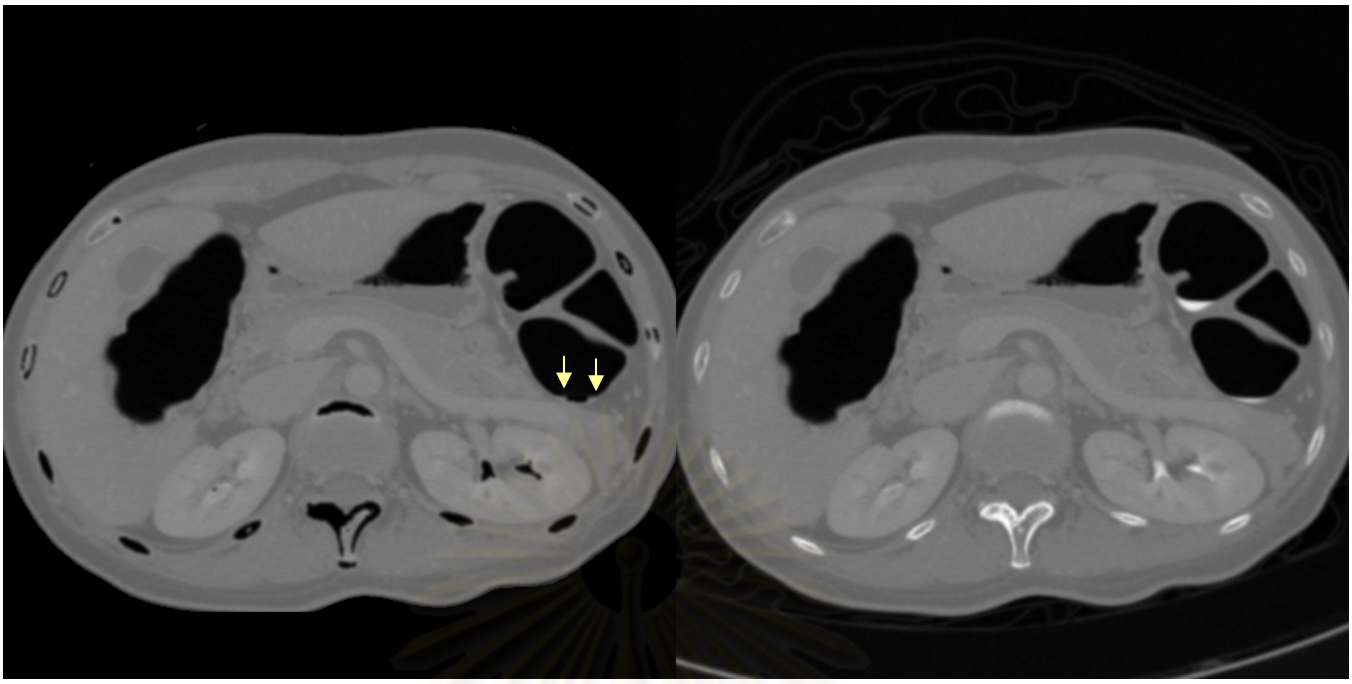

Figure 3.8: Left image is the result from proposed method. Right is the original abdominal CT-scan image.

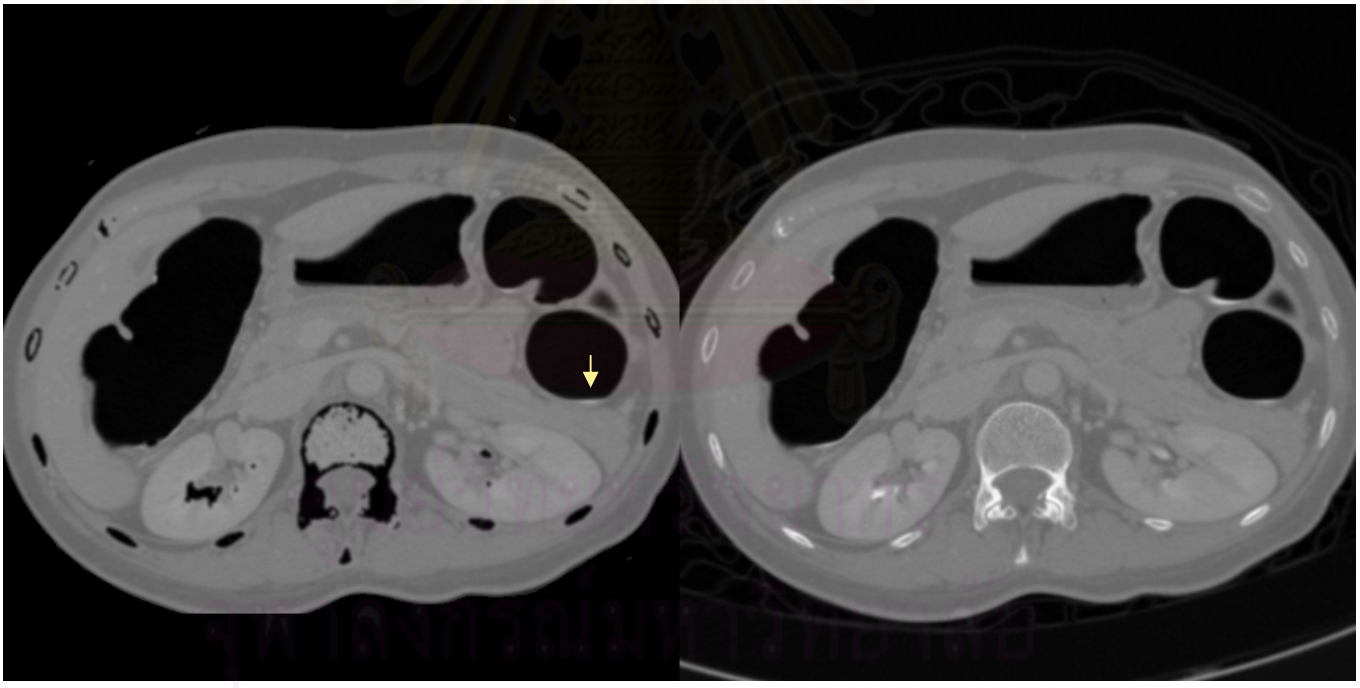

Figure 3.9: Left image is the result form proposed method. Right is the original abdominal CT-scan image.

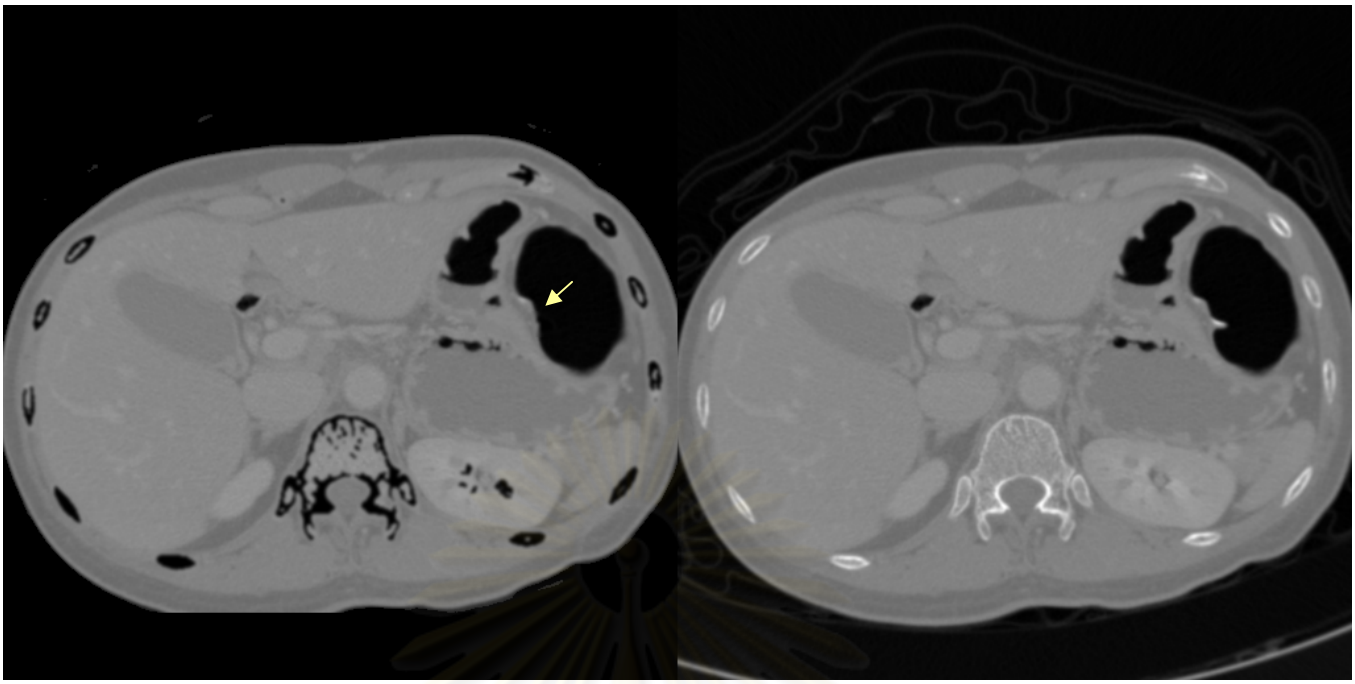

Figure 3.10: Left image is the result from proposed method. Right is the original abdominal CT-scan image.

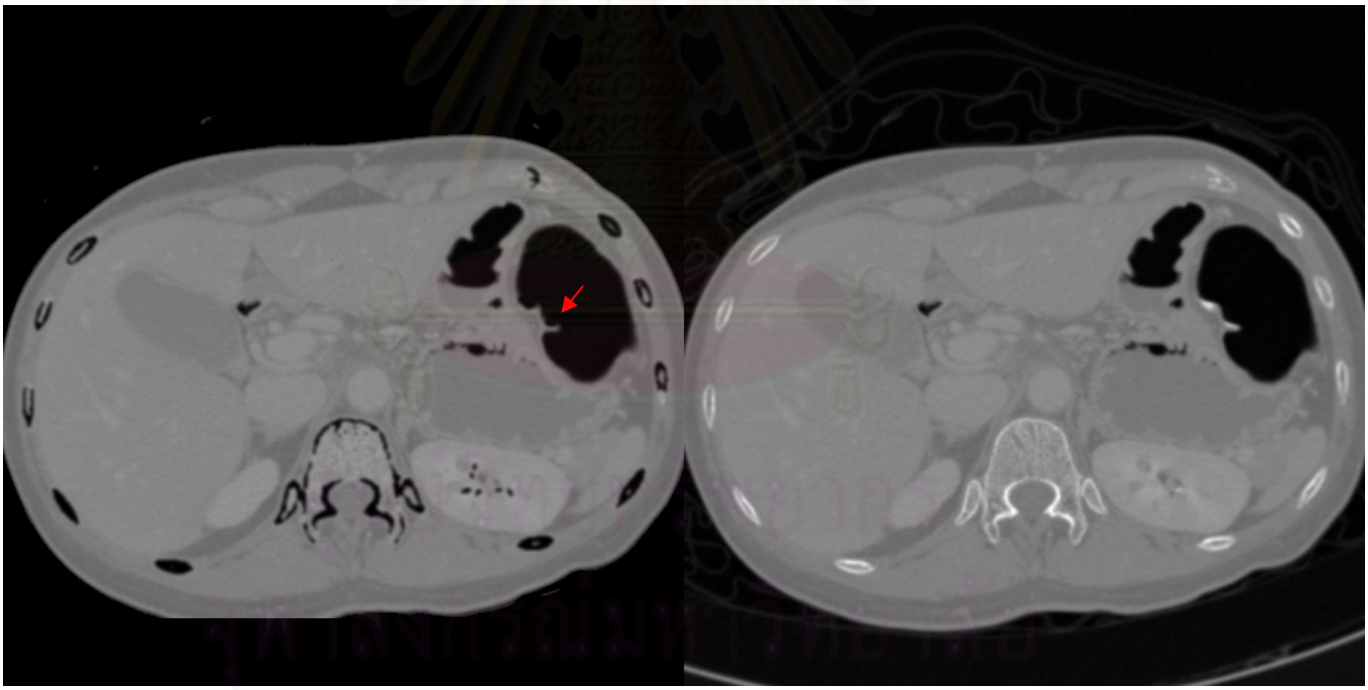

Figure 3.11: Left image is the result from proposed method. Right is the original abdominal CT-scan image.

For conclusion of this kind of sensitivity will be mentioned again in factor analysis section. The conclusion for this section is a few case of the colon cleansing in our proposed method is not efficient and give an explanation why it is but the most case of our proposed method work properly as in the next section that shows the evolution of our proposed method by physician.

3.2 Comparison results

The comparison result shows just our evaluation result in statistical version because there is still limitation that we could not use the same sample or data as related work and also we could not use other work to exam our data. The experimental results were evaluated by the physician under two criteria: percentage of cleansing and confidence score on accuracy. The percentage of cleansing is divided into 5 levels of completeness where level 1 means 0-25%, level 2 means 26-50%, level 3 means 51-75%, level 4 means 75-99%, and level 5 means 100%. The confidence score on accuracy is divided into 4 levels of confidence on the results where level 0 means no confidence, level 1 means low confidence, level 2 means moderate confidence, and level 3 means high confidence. Table 1 shows percentage of cleansing and table 2 shows confidence score on accuracy on four datasets of two patients.

Case	Level 1	Level 2	Level 3	Level 4	Level 5
Case#1 prone	9.94%	0%	0%	1.84%	88.21%
Case#1 supine	12.68%	1.87%	0.72%	0.43%	84.29%
Case#1 prone	17.91%	2.09%	2.39%	4.78%	72.84%
Case#2 supine	11.07%	0%	0%	6.56%	82.38%
Average	12.9%	0.99%	0.78%	3.4%	81.93%

Table 3.1: Percentage of cleansing

Case	Level 0	Level 1	Level 2	Level 3
Case#1 prone	7%	0%	0.74%	92.27%
Case#1 supine	14.84%	0.29%	0.58%	84.44%
Case#2 prone	14.93%	7.46%	5.07%	72.54%
Case#2 supine	11.46%	0%	11.07%	77.45%
average	12.06%	1.94%	4.37%	81.68%

Table 3.2: Confidence score on accuracy

3.3 Factor analysis result

Our proposed method depends on two main algorithms which are Canny's edge detection parameter selection and similarity measure. An important parameter which is σ as we know that if this value is high, it makes image blur and distorts the image information especially at boundary of objects in image and if this value is low, it cannot remove the suffering from noise in image which results in wrong edge boundary because the pulse of noise can activate edge detection to detect this spike. The other one is similarity measure, it groups similar pixels into belonging group without concerning about local spatial intensity that is too sensitive to assign into the right group.

Another possibility for the efficient results is the patient preparation. If the patient preparation is not very well especially where the tagging solution cannot tag the fecal inside colon in every corner or is too dilute to enhance the contrast between tissue and fecal tagging or to identify fecal tagging material and turn out to be tissue because of its contrast.

However, the efficiency of our results is still good enough. The evaluation from the physician is used to explain how good and bad our method can perform. The evaluation shows that the mistakes as shown in previous section is not that many and the result is in a fair level. The number of data sets that is used to test our proposed method

is still very low to confirm our proposed method for real world commercial software. It needs a lot more data set to confirm our proposed method and improve it but now the principle that is used in this proposed method has been accepted from this evaluation.

Next chapter we will conclude what we have done in conclusion and more discussion about our proposed method and future work about what we are going to do next for related research

CHAPTER IV

Conclusion and Future work

4.1 Conclusion

This thesis purposes a new method for EC method. Unlike existing EC methods, this method subtracts a fecal tagging material region by using the Canny's edge detection for capturing the boundary of colon, interpolation, hole-filling, the similarity function for fecal tagging material region, and the reconstruction of Gaussian's blurring and averaging filter. Moreover, this method was shown successfully to preserve the thin tissue layer adhering to fecal tagging material regions while removing the AT boundaries; thus, it could effectively remove the artifacts of pseudo soft-tissue structure.

4.2 Discussion

From the experimental results on fours sets, we can see that our proposed method can clean the fecal tagging materials that are remained in the colon regardless of their positions. As can be seen from Fig. 3.1 that tagged materials located at normal position can be cleaned efficiently, especially at the position pointed by an arrow at lower right corner, it can be seen that tagged material is removed while colonic walls is kept untouched. Fig. 3.2-3.6 shows the removal of fecal tagging materials by arrows (pointed from a prone-posed image where the positions of tagged material are located up-side down). The air-tissue AT layer and high density region are successfully removed from the original image, then the images is enhanced during the reconstruction in order to generate new smooth boundary between air and tissue. However, the partial volume effect or PVE between three components: air, tissue, and enhance material still remains in some of the resulted images due to the problem that this intensity is in the same range between two classes. The similarity function is used to avoid biased intensity value of high density pixels. The time consumed per CT-scan slice image is between 20 seconds to 3 minutes. Although the program is not essentially concerned with time rate due to the relatively unurgent nature of the subject, colon cancer detection, the speed is still subject to improvement.

4.3 Future work

In future work we try to extend our work into 3-dimensional and look for new method that reduce computational time in colon cleansing method because a data set is quite huge with number of pixels or voxels (3-dimensional). The drawback from the evaluation method is a few numbers of samples for experiment. The number of data set that is used to examine should be a large number of patient in future work to confirm the result and method. In this paper is just a pilot case which starts our idea and initiates the project with a few cases in the beginning for possibility to continue our project into larger volume of experiment. The authors also expect to create virtual colonoscopy with new methodology in future to use in our own country because the software for virtual colonoscopy is costly so it would be great if we could invent our own software to save the cost. The full automatic system for virtual colonoscopy needs colon cleansing method, simulation of 3-Dimensional colon surface inside and outside structure, the navigation inside the colon, and the distance measurement from anus to suspect region or volume.

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APPENDIX

APPENDIX A

This section will give a review on popular edge detector as promising in Chapter II. The popular edge detection are Sobel , Prewitt, Roberts, and Laplacian of Gaussian (Log). Before we can that far we will give a review to the convolution concept.

1.Convolution

The linear operation calculates the resulting value in the output image pixel $g(x,y)$ as a linear combination of brightness in a local neighborhood N of the pixel $f(x,y)$ in the input image. The contribution of the pixels in the neighborhood N is weighted by coefficient, c :

$$f(x,y) = \sum_{(a,b)\in \mathrm{N}} \sum c(x-a, y-b) * g(a,b)$$

The example

$$c = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 7 & 8 & 9 \end{bmatrix} \quad and \quad g = \begin{bmatrix} -1 & 2 & -3 \\ 4 & -5 & 6 \\ -7 & 8 & -9 \end{bmatrix}$$

To perform convolution operation between c and g yield:

$$f(2,2) = c(1,1) * g(1,1) + c(1,2) * g(1,2) + c(1,3) * g(1,3) + c(2,1) * g(2,1) + c(2,2) * g(2,2) + c(2,3) * g(2,3) + c(3,1) * g(3,1) + c(3,2) * g(3,2) + c(3,3) * g(3,3)$$

2.Sobel's edge detection

This operator is mostly used in horizontal direction and vertical direction of edge by using following mask:

$$vertical\_mask = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

$$horizontal\_mak = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

These two mask are used to convolute with pixel one by one in both x and y direction and then find the strength of edge by:

$$\sqrt{I_x(x,y)^2 + I_y(x,y)^2} \qquad or \qquad \left|I_x(x,y)\right| + \left|I_y(x,y)\right|$$

Where I is an image. $I_x = I * vertical\_mask$, $I_y = I * horizontal\_mask$ and direction of edge is $\arctan\left(\frac{I_x}{I_y}\right)$.

3.Prewitt's edge detection

The prewitt's edge detector is similar to Sobel which is used the approximation of first derivative by estimating the gradient with 3×3 mask in eight direction. The gradient in each direction can calculate by each mask of direction. The direction of edge can be found by finding the maximum response from each mask. The example is given mask in vertical and horizontal direction as follow:

$$vertical\_mask = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$horizontal\_mask = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

The drawback of edge detectors (Prewitt and Sobel) is the size of object cannot be vary and very sensitive to noise.

4.Robert's edge detection

Robert's edge detector is simplest edge operator because of its mask that is used to convolution with pixels in an image as follow:

$$m_1 = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \quad and \quad m_2 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

The magnitude of edge can calculate by:

$$|A_9 - A_5| + |A_8 - A_6|$$

Where A is the convolution result and $A = \begin{bmatrix} A_1 & A_2 & A_3 \\ A_4 & A_5 & A_6 \\ A_7 & A_8 & A_9 \end{bmatrix}$.

The main drawback is sensitivity to noise because very few pixels are used to estimate the gradient.

5.Laplacian of Guassian edge detection

The Laplacian of Guassain aims to find the second derivative of a smoothed 2D function $G(x, y, \sigma)$ so Laplacian of Guassian looks like this:

$$Log = \nabla^2 [G(x, y, \sigma) * I(x, y)]$$

When $G(x, y) = \frac{1}{2\pi\sigma^2} * e^{-(x^2+y^2)/2\sigma^2}$ and I is an image. The example of mask 3×3 where $\sigma = 0.5$ is:

$$h = \begin{bmatrix} 0.4038 & 0.8021 & 0.4038 \\ 0.8021 & -4.8233 & 0.8021 \\ 0.4038 & 0.8021 & 0.4038 \end{bmatrix}$$

The main drawback is the edge responsibility is double to some edges in an image.

VITAE

EDUCATION & HONORS

B.S. in Mathematics,Chulalongkorn University,Thailand,2006

LANGUAGE: Thai,English

WORK EXPERIENCE:

- Exchange student at National Institute of Informatics, Japan.
- Assistance researcher.
- High school tutor in mathematics and Physics.

Publication:

Krisorn Chunhapongpipat, Laddawan Vajragupta, Bundit Chaopathomkul, Nagul Cooharojananone, and Rajalida Lipikorn. Automatic Colon Cleansing in CTC Image using Gradient Magnitude and Similarity Measure. Springer-Verlag Berlin HeidelBerg CCIS 61:82-89