Image Segmentation of Thyroid SPECT Using Edge-Based Active Contour Model

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Abstract. Nuclear medicine is a reliable method to analyze or diagnose some type of diseases using functional imaging, for example SPECT imaging to obtain organs uptake and biodistribution. In order to get information needed, SPECT images have to be segmented first. Region of interest (ROI) method by the expertise is generally performed for image segmentation in SPECT imaging, but the task is daunting and time-consuming due to large number of images to be segmented. Among many methods that can be used for image segmentation, edge-based active contour is one of the most popular and widely used method in medical image segmentation. In addition to Level Set Method that fails to stop gradient magnitude by only using gradient information, here the edge-stop function (ESF) is proposed for edge-based active contour models to segment images with unclear boundaries using Matlab R2019a. In this study the Level Set Method with k-Nearest Neighbours classifier and fuzzy ESF are used to segment the thyroid images from the 99mTc-sestamibi SPECT imaging. The number of iterations and initialization are assessed to obtain better segmented images which closely related to segmented images using ROI technique from the experts. The results showed that the proposed method could be used for segmentation of thyroid SPECT images.

Keywords: SPECT, gamma camera, active contour, segmentation, thyroid, 99mTc, sestamibi

1. Introduction

Nuclear medicine is a branch of science that uses unsealed radioactive sources from radionuclide to study physiological and biochemical changes and can be used for diagnostic, therapeutic and research purposes in medicine [1]. It is used in diagnosing various medical cases, especially in the assessment of organ function and cell metabolism through scanned images. Nuclear medicine activities for diagnostic purposes are based on two methods, in vivo and in vitro. In in vitro studies radioisotopes are only reacted with biological material (blood, urine, cerebrospinal fluid, etc.) taken from the patient's body. Whereas an in vivo study, radioisotopes can be inserted into the patient's body by inhalation through the airway, oral, or by injection [2].

Nuclear medicine imaging uses a gamma camera or positron camera as the main equipment and results in functional images which give description on the function of organ or tissues. The result is based on biochemical-physiological changes that give rise to radiation emission patterns as a
representation of the function of organs or tissues [3]. The gamma camera is composed of a collimator, a scintillator crystal usually made of natrium iodide (NaI), the photomultiplier tubes, the electronic circuits and a computer equipped with software to depict the nuclear medicine examinations. There are two main methods of patient imaging, planar imaging and dynamic imaging. In planar imaging the counts measured in a specific planar projection originate from the whole thickness of patient, while in dynamic imaging the gamma camera head rotates around the patient remaining at well-defined angles and acquiring counts for specific periods of time per angle [4].

Thyroid is the largest pure endocrine gland in the human body located in the area of neck, consisting of two parts, the left and right lobes. The length of each lobe is about 5 cm and merges in the midline of the body, with a shape like a butterfly. Thyroid hormones have a very important role in various metabolic processes and some physiological activities in human organ systems [5]. Thyroid imaging using gamma cameras is a practice of in vivo studies [6]. After being inserted into the body, radioisotopes in the body can be examined by several methods to obtain images of organ, parts of the body, or even the whole body. Images are further processed to obtain the curves or numbers that represent the functions of organs or parts of the body being examined [2].

Nuclear medicine uses radionuclides which are generally labelled with some pharmaceuticals and form the radiopharmaceuticals to be injected inside the body. Several radiopharmaceuticals used in thyroid imaging are $^{131}$I and $^{99m}$Tc-Sestamibi (Mibi). In this study, $^{99m}$Tc-Sestamibi (Mibi) is used as a tracer for SPECT imaging with a gamma camera. Mibi is found in some areas of face, especially in the thyroid and parathyroid organs and some other organs in the body (in full body scanning) [6]. Visual inspection of $^{99m}$Tc-Sestamibi scanning images on the thyroid can be done after Mibi deposits occur in thyroid tissue, for example in nodular and extranodular [7].

Although nuclear medicine imaging is superior in giving information on organ function, it suffers from low resolution. The challenge is more when image segmentation is performed to obtain function of organ related with the counts of absorbed radiopharmaceuticals on specific organ. The images generally have unclear boundaries that are often difficult to be segmented in order to obtain the information needed. Region-of-interest (ROI) techniques are generally carried out in nuclear medicine practice by manually segment the images based on visual inspection by the expertise. The task is daunting and time-consuming due to large number of images to be segmented. The effective method for auto segmentation is needed to assist and validate ROI technique in thyroid SPECT imaging.

Image segmentation using an active contour model is a technique that is widely used in image processing. In the snake model, the initial contour of a snake-like shape is arranged and then dynamically adjusts to the edge of object in the image. The technique is excellent for image segmentation but does not work efficiently for images with non-homogeneous intensity. The development of the snake model is a level-set method in which active contour models (snake models) are combined with geometric models. The level-set method is a technique used to track interfaces and shapes. In higher dimensional functions, the contour of the level-set method is defined as zero level set, known as a level-set function [8]. Level-set methods can overcome the problem of topological changes in contours or surfaces during the evolution process [9].

The edge-stop function, $g$, is a function used to detect edges of the surface contour evolution. In active contour models based on curvature, edge-stop functions $g$ is defined by [10]

$$g(x,y) = \frac{1}{1 + |\nabla I(x,y)|^\alpha}$$

where $I$ is an image in the domain and $G$ is a Gaussian with a standard deviation. The edge-stop function plays a role in stopping the evolution of contours and can be developed by making decisions not only considering gradient information but also the number of parameter values in the classification of pixels in the boundary region [11].
In the Fuzzy Integrated Active Contour Model (FIACM) model, the edge-stop function is determined based on posterior probability. The edge-stop function (ESF) influences the final outcomes of the evolution of surfaces. The function is used in medical images with low contrast and blurred boundaries. Because the image does not contain the ideal edge, the edge-stop function, $g$, must be determined [10]. In this study the fuzzy edge stop function, $\rho$, is used which is based on the probability score, $s$, for the foreground along with $k$-Nearest Neighbour as the classification method

$$\rho(s) = (2(s - 0.5))^2. \tag{2}$$

The value of $g$ is determined using the probability score above to get the new edge stop function, $g_{\text{new}}$ which is defined as [11]

$$g_{\text{new}} = g \rho. \tag{3}$$

In this study, image segmentation from SPECT images of thyroid using $^{99m}$Tc-Sestamibi gamma camera is conducted using edge-based active contour method based on the new edge-stop function (ESF). The image initialization and number of iterations are assessed to find the best segmented image which closely related with ROI images from expertise.

## 2. Materials and Methods

### 2.1. Image Acquisition

SPECT imaging from six volunteers is carried out with the help of Nuclear Medicine Practitioners in the following steps.

1. $^{99m}$Tc-Sestamibi as the radiopharmaceutical properties is made by mixing $^{99m}$Tc with Sestamibi which has been prepared. The two ingredients are mixed directly in a shielding syringe which is also a syringe used for injection of the radiopharmaceutical to the patient later.

2. $^{99m}$Tc-Sestamibi activity is measured using dose calibrator before the elution process.

3. The radiopharmaceutical activity is scanned to get background count by placing and scanning shielding syringe on gamma camera table.

4. $^{99m}$Tc-Sestamibi radiopharmaceutical is injected intravenously into the patient's arm with dose of about 8-11 mCi. After 10 minutes, the volunteer lies on the patient's bed (examination table) with the camera is positioned in front of the volunteer with a 7 cm distance. Image acquisition is conducted using planar methods. The gamma camera head remains stable at a fixed position over the volunteer for a certain period of time.

### 2.2. Image Segmentation

Image segmentation is performed using Matlab R2019a (Mathworks, US) by processing grayscale images from SPECT imaging. The grayscale images are marked and defined as a ground truth for image initialization. In our experiment, an edge-stop function is implemented with standard parameters for all images in accordance with the article [11]. The number of neighbors, $k = 99$ is used for all experiments to cover the number of different intensity values and produce a smooth transition between the background and foreground around boundary.

The press fuzzy edge-stop function is used according to equation (2) to regulate the function of $g$ in equation (1) and get new function in equation (3). If in general $k$-Nearest Neighbors classifies data based on majority voting, probability scores are used here which are implemented on fuzzy $k$-Nearest Neighbors. The Gaussian is applied for filtering and smoothing to overcome noise and prevent the contour from stopping prematurely. The new function is used instead of the function in equation (1) for objects with unclear boundaries. After obtaining the desired segmentation results, then the object area is calculated based on the number of pixels in the segmented thyroid images.
3. Results and Discussion

Figure 1 is an example of an original image from SPECT imaging and figure 2 is part to be processed from a grayscale image, which will later become an input image. Figure 3 and figure 4 are grayscale images that have been marked and ground truth as another input images and will be the basis for image initialization. Red mark represents the foreground and blue mark is the background, which later will be an initialization to get area of interest.

The image $g$, an interpretation of ESF which uses only the gradient information is shown in figure 5. Fuzzy ESF $(\rho)$ from the equation (1) is applied to probability scores and the resulting map is shown in figure 6. Figure 7 which is based on equation (2) is the new edge-stop function of the edge-based active contour model. These are the processed images that will lead contour to get edge of object.
Initialization as an important part in image segmentation will determine the result of segmentation, especially for edge-based active contour models [11]. This problem of initialization is solved by using the type of foreground that will make it easier for contour to expand. In our experiment, the foreground in the form of a red mark covers some areas or parts because it has an intensity that equals to the background in the middle of thyroid. This method is effective where a contour is obtained after the active contour images develop outward from the initial initialization to obtain the edge of thyroid. SPECT image segmentation are also generated with various number of iterations in order to find the best results. Images with the higher number of iterations gives the better segmented image which is close to ROI images from the expertise in our experiment. Images with 510 iterations generate better results and closer to the ground truth image than images with 385 and 260 iterations.

In general, the proposed method is effective for segmenting thyroid SPECT images. With these common parameters, active edge-based contours can meet at the boundary edges of objects according to the definition of $U$. The growing contour stops before it reaches the edge in the images that has intensity corresponding to the blue mark or background and applied to all images. The results of segmentation are comparable to the ground truth images as shown in figure 8 and figure 9.

The area of thyroid is obtained by calculating the segmented image pixels. Based on the segmented image, the area that obtained is only the thyroid part that absorbs injected radiopharmaceuticals for certain amount of intensity. The comparison of segmented thyroid area with area of ROI is given in Table 1. The results at Table 1 show that the proposed method is sufficient for image segmentation of thyroid SPECT images. However, some parameters, such as initialization and number of iterations must be optimized to produce better segmented images.

| Volunteer | Area by ROI (cm²) | Area by proposed method (cm²) |
|-----------|-------------------|-----------------------------|
| A         | 21.2              | 20.14                       |
| B         | 16.7              | 14.28                       |
| C         | 16.3              | 15.66                       |
| D         | 20.5              | 19.38                       |
| E         | 15.9              | 5.41                        |
| F         | 16.9              | 15.58                       |
4. Conclusion
The implementation of active contour model to segment thyroid SPECT images have been conducted using the new ESF. It is concluded that proposed method can be used to generate segmentation results by using greater iteration numbers and most importantly, proper user initialization. The results of thyroid area show nice trend compared to conventional ROI method except volunteer E. It shows that this method is dependent on the image intensities and characteristics.

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