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An Overview of Medical Image Segmentation and Registration in Magnetic Resonance Imaging (MRI)

Abstract – In the medical imaging field, medical image segmentation and image registration have been two of the major areas of research which is constantly evolving from time to time based on the continuous improvement of technology and image analysis techniques. This review will thus give an overview of the methods used for image segmentation and registration in the Magnetic Resonance Imaging (MRI) application. It will discuss the past and current methods which are already in practice facilitating MRI image analysis and also discuss future methods of conducting image segmentation and registration which are still under research which might someday, significantly improve the already existing methods.

I. INTRODUCTION

Currently, there are numerous medical imaging techniques such as MRI, CT, PET and many others which are used to analyse, monitor and create a visual representation of the various aspects and functionalities of the human body. These techniques require different methods to develop medical images from their respective sources. The main goal of these methods is to enable a more meaningful and easier representation of the medical images.

In an MRI application, one is able to obtain images of the anatomy and the physiological processes of the body by placing the patient under observation into an MRI scanner which uses strong magnetic fields, radio waves and field gradients to generate a medical image.

Image Segmentation refers to the process of subdividing these medical images into multiple smaller segments whereby each pixel in the image is assigned a label having a particular characteristic. Some applications of image segmentation in MRI include locating tumours, measuring tissue volume, studying anatomical structures and many others.

Image Registration on the other hand, is the process of integrating different sets of data points from different images to infer correspondence to the features (these are identified in the images) [1].

The review continues to further explain the methods of segmentation and registration in depth, citing a number of researches and their results and finally concluding by summarizing the key points discussed in the review and explaining their significance.

II. METHODS OF IMAGE SEGMENTATION

Medical image segmentation usually results in a set of multiple segments covering an entire image under inspection. Prior to image segmentation, some steps which involves reading the image files, enhancing the image and feature detection must be performed. Segmentation methods usually have two approaches to choose from; one being a Discontinuity based approach and the other one being a Similarity-based approach. The following are some of the methods used in both of these approaches in the medical image segmentation process:

A. SIMILARITY-BASED APPROACH IN IMAGE SEGMENTATION

Methods used in this approach detect changes in the brightness, orientation and gradient in the region of an image under inspection. Some methods following this approach include:

1. Region Growing:

This is one of the earlier region-based segmentation approach which involves selection of initial pixels (growing seeds). The method determines whether the neighbouring pixels of the initial seed points are to be added to the region or not depending on a predefined criterion (can be pixel intensity, pixel colour or even greyscale texture). This criterion if used continuously, would result in the region to grow [2]. The main merit of this method is that it only requires a small amount of initial seed points to start the segmentation process. An improved method which is more immune to noise, is discussed in [3] which provides better MRI images to efficiently detect tumours and brain abnormalities.

2. Thresholding:

This is one of the simplest and earliest methods of image segmentation which divides the pixels of the image with respect to their intensity level. The method works by first selecting grey scale values for each pixel and choosing an appropriate threshold value from the grey scale and then classifying the image regions into background and foreground [4]. Currently there are several methods to conduct thresholding which include statistical method (by plotting histogram to figure out the suitable threshold value), Adaptive thresholding (by calculating different thresholding values for different regions of the same image) and many others. These methods however manually calculate the thresholding value and thus a better approach like the Otsu's method (algorithm which determines the threshold value automatically by minimizing the intra-class variance) is used [5]. These existing methods are mostly bi-level meaning using two levels to categorize the image, which is not suitable for an MRI application as MRI contains many different parts. Thus, a multi-level thresholding method like the Swarm optimization algorithm must be used. This method mimics the swarm behaviour from fish/birds to provide with optimal threshold value to minimize the sum within a class variance [6].

3. Clustering:

This method segments the image into clusters containing pixels with similar characteristics. This was an early method for image segmentation but with time, its algorithms got optimized for better efficiency. The earlier clustering method was called the K-means which categorized each pixel with the nearest obtained mean of the image [7]. The K-based algorithm did converge but was not giving optimal results as it depended on the initial set of clusters and the manual chosen K-value. Thus, a modified, optimized version called Fuzzy C-means (FCM) was developed which automatically governs the K-value through statistical information. It is sometimes also referred to as the soft clustering or the soft K-means. This method involves assigning each tissue with a cluster which contains specific data for that tissue and thus creating a label to each data. Here, each data point has a possibility to belong to more than one cluster. These clustered data must be similar based on a Euclidian similarity criterion [5].

4. Watershed Algorithm:

This method is derived from a geographical phenomenon of topological interpretation. Here, the greyscale level of an MRI image pixel is interpreted as the height of this geographical topology where each pixel is represented as a surrounding of watershed line containing water flowing downhill towards a local minima [8]. The pixels having more gradient are interpreted as continuous boundaries and the segments are represented as basins formed when 'pixels' drain to the common minima. These watershed lines may be defined as either nodes or edges on a graph to conduct image segmentation. The advantage of the watershed method is that its detected boundaries are continuous and stable in nature. However, the downside of getting stable results is that it usually involves complex gradient calculations [9].

5. Artificial Neural Network:

This method simulates the learning strategies of the brain for the aim of decision making. It is one of the latest methods used for image segmentation due to the uprising advancements in Artificial Intelligence. It involves a connection of large number of artificial nodes and each connection is assigned with a specific weighting which helps to separate the medical image from its background. This method provides with an easier and more efficient segmentation process, but it consumes a lot of time in training the neural networks [4].

B. DISCONTINUITY-BASED APPROACH IN IMAGE SEGMENTATION

Methods used in this approach detect changes in the lines, edges and points in the boundary of an image under inspection. Some methods following this approach include:

1. Edge Detection:

This is the most common method used in this approach, which helps to detect significant discontinuities in greyscale levels. An edge refers to a collection of pixels which lie on the boundary between two regions of the image. In general, the edge detection method uses gradient filters to detect edges using techniques like the Sobel operator, Robert's operator and the Canny Edge Detector (multi-stage algorithm which detects wide range of edges) [9]. One of the advantages of this method is that it can be widely used for images which have better contrast between objects but with a limitation that it must not contain too many edges.

2. Line and Point Detection:

These methods are not widely used nowadays as edge detection dominates the discontinuity-based approach in image segmentation. Point detection simply detects isolated points (points having different greyscale than its background) in an image using a mask. Similarly, a line detection detects points in a line (orientated either horizontally, vertically or at a 45° angle), and then associates that line to a mask in that specific direction [8].

III. METHODS OF IMAGE REGISTRATION

Image Registration is the process of integrating different sets of data points from different images to infer correspondence between them. Image registration requires to first pre-process the image using image segmentation methods and then conduct feature selection and correspondence techniques in order to transform the function determination and finally resample the images.

In an MRI, the registration methods are used to co-register images to each other or to images obtained from other modalities. Some methods used for MRI registration are discussed below:

A. Principal Axis Algorithm:

This method is a simple, straightforward algorithm which automatically determines the rotation and translation aligning the source image to the target. It involves calculating the eigen vectors and centroids of the source image and the target and then aligning the centre of masses via a translation vector to eventually align the image [10]. Although this method is considered very simple to implement, it does miss out sensitive information as it just provides with a close approximation of the real image. Thus, better methods as discussed below may be used for better results.

B. Intensity-based Automatic Image Registration (AIR):

This is a more powerful method for image registration as it is very robust and flexible. AIR is an iterative, automated algorithm that can be used in multi-modalities. It involves selecting a 2D-transformation type and transformation matrix which aligns the moving image with the reference image and developing a similarity metric between these two images. Finally, an optimizer is used to either maximize or minimize this metric and begin the next iteration [8]. The transformations obtained in this method will be consistent throughout the whole image making it a very robust method, but the computations involved in this algorithm are very complex.

C. Wavelet-based Image Registration:

Wavelets are oscillatory functions with a zero average value chosen based on their ability to analyse the signal. This method is usually proceeded after conducting the Intensity-based AIR and a discrete wavelet transform is applied to the referenced image which undergoes a decomposition through a filter to obtain fused images that contain data from both the moving and the fixed images [11]. The quality of these fused images depends on the entropy, correlation coefficient, mean square error and the peak signal to noise ratio of the image. This method is an advancement of the AIR and is thus more efficient in integrating data points between the two images and having a good correspondence coefficient for the image registration.

IV. CONCLUSION

A literature review for an overview of Medical Image Segmentation and Image Registration in MRI was carried out and a detailed discussion on the methods used for each of the above aspects were clearly outlined.

In Image Segmentation, two main approaches namely, the similar and discontinuous-based approaches were discussed and the methods for each one of the approaches were explained in depth. Pros and cons for most of these methods were also discussed. A newer method like the artificial neural network was brought to light signifying the continuous advancements in science and technology and hinting at more developments in segmentation as efficiency and automation can always be enhanced. In Image Registration, the methods used were discussed along with their respective merits and demerits and the parameters that measure the quality of the fused image were mentioned.

Apart from the methods mentioned in this review, there exists a vast ocean of many more techniques for image segmentation and registration which can be accessed from various surveys and journals separately from the ones cited below.

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