Validation of Graph Theoretic Segmentation of the Pectoral Muscle

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Abstract. Two graph theoretic methods are used in conjunction with active contours to segment the pectoral muscle in 82 screening mammograms. To validate the method, the boundaries are also marked by four radiologists with different levels of experience in mammography. The simultaneous truth and performance level estimation (STAPLE) method is used to estimate the true boundary and to estimate the sensitivity and specificity of the segmentation schemes. The performance of one of the two algorithms is found not differ significantly from radiologists.

1 Introduction

In order to develop or compare algorithms for segmentation, it is necessary to estimate the level of accuracy by some criterion. Often, the best available method is to ask a radiologist or other expert to segment the image manually and use the resulting boundaries as the true boundaries. The difficulty is that boundaries drawn by different experts usually do not agree. Such validation problems are ubiquitous in medical image analysis.

Recently, a method was devised for estimating the true boundary given a set of boundaries drawn by experts. The method, called simultaneous truth and performance level estimation (STAPLE) [1] is based on the expectation-maximization (EM) algorithm. The method also provides estimates of the performance of segmentation algorithms in terms of sensitivity and specificity.

Here we report on the use of STAPLE to estimate the performance of two segmentation algorithms based on graph theory, the adaptive pyramid (AP) algorithm [2] and the minimum spanning tree algorithm (MST) [3]. These algorithms were used to find the pectoral muscle in screening mammograms.

The pectoral muscle is only of marginal clinical interest. However, for automatic detection of breast cancer using computers, the pectoral muscle represents a region where the intensity statistics are likely be quite different from the rest of the image. Hence it is convenient to identify this region in order to apply different processing steps or to ignore it entirely. The pectoral muscle is also a significant landmark for use in automated image registration. Finally, in developing new methods for segmenting mammograms, or medical images in general, identifying the pectoral muscle is a convenient initial test.

Thus neither the objective of the study (the detection of the pectoral muscle) nor the method (STAPLE) directly improve clinical detection of breast cancer.

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Both the task and the method are aimed at improving studies on computer-aided detection of breast cancer.

2 Graph Theoretic Segmentation and Active Contours

A graph, $G = (V, E)$ consists of a set of vertices, V, and a set of edges, E. An edge, $e \in E$, consists of pair of vertices, $e = (v_i, v_j)$, where $v_i, v_j \in V$. In the case of image segmentation, V is the set of pixels and E determines which pixels are viewed as being associated. In this setting, image segmentation is equivalent to finding (disjoint) subgraphs of G.

2.1 AP Algorithm

The AP algorithm builds sequences of ever smaller graphs. This sequence of graphs is often pictured as a pyramid with the original full graph forming the base of the pyramid and successive graphs forming smaller and smaller layers above. At the base level, the graph consists of V_0, the set of all pixels in the image, and E is such that every pixel is joined to its immediate eight neighbors. A vertex survives to the next level if it is more representative of its immediate neighborhood than are its neighbors. If two pixels are connected by an edge, then both are not allowed to survive to the next level. Also, for every pixel, at least one of the pixels to which it is connected survives to the next level. Two surviving pixels are connected in the next level if the regions they represent in the previous level have similar mean intensity but not otherwise. If a surviving pixel does not represent a region in the previous level similar to other surviving pixels, this surviving pixel is called a root. Passing back down the layers of graphs, root pixels identify a subset of V that is accepted as a region of the image [2],[4].

2.2 MST Algorithm

The MST algorithm starts with the graph such that V is the set of all pixels and E is the empty set. However, there is a set of candidate edges E_c consisting of all edges that join pixels to other pixels in small neighborhood. All the edges in E_c are assigned an edge weight that measures how well the two pixels comprising the edge match according to a pre-defined criterion. These candidate edges are ordered by increasing edge weight.

Starting with the edge with smallest weight, each edge is considered for inclusion in the final graph. An edge is accepted if the two vertices are in disjoint components of the current graph and the edge weight is small compared to the internal variation within the two components. Once all the candidate edges in E_c have been considered, V together with all the accepted edges is the final graph. The disjoint subgraphs of the final graph form the segmentation [3],[5].

2.3 Active Contour

The AP and MST algorithms were generally found to identify the pectoral muscle in terms of general location and shape. However, the edges of the components