Computers in Biology and Medicine 50 (2014) 76–96

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

A review on segmentation of positron emission tomography images

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ARTICLE INFO

Article history:
Received 17 August 2013
Accepted 16 April 2014

Keywords:
Image segmentation
PET
SUV
Thresholding
PET-CT
MRI-PET
Review

ABSTRACT

Positron Emission Tomography (PET), a non-invasive functional imaging method at the molecular level, images the distribution of biologically targeted radiotracers with high sensitivity. PET imaging provides detailed quantitative information about many diseases and is often used to evaluate inflammation, infection, and cancer by detecting emitted photons from a radiotracer localized to abnormal cells. In order to differentiate abnormal tissue from surrounding areas in PET images, image segmentation methods play a vital role; therefore, accurate image segmentation is often necessary for proper disease detection, diagnosis, treatment planning, and follow-ups. In this review paper, we present state-of-the-art PET image segmentation methods, as well as the recent advances in image segmentation techniques. In order to make this manuscript self-contained, we also briefly explain the fundamentals of PET imaging, the challenges of diagnostic PET image analysis, and the effects of these challenges on the segmentation results.

Published by Elsevier Ltd.

Contents

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http://dx.doi.org/10.1016/j.compbiomed.2014.04.014
0010-4825/Published by Elsevier Ltd.

1. Introduction

Structural imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) are widely utilized in clinical practice to examine anatomical abnormalities caused by disease. The three dimensional (3D) images produced by these techniques usually give detailed structural information about one's anatomy that can be used for diagnostic and therapeutic purposes [1]. However, structural imaging is not well suited for pathology detection applications where *cellular activity* is more significant than anatomical features [2]. The need for functional characterization leads researchers to develop PET scanners, which provide molecular information on the biology of many diseases. When combined with CT or MRI, utilizing both functional (PET) and structural information leads to a higher sensitivity and specificity than is achievable using either modality alone. Although the sensitivity of PET scans is usually much higher than conventional structural images, anatomical information from another modality (CT or MRI) is still needed to properly interpret and localize the radiotracer uptake and the PET images are somewhat limited due to low resolution. Hence, there is a frequent need for assessing functional images together with structural images in order to localize functional abnormalities and distinguish them from normal uptake of PET radiotracers, which tend to normally accumulate in the brain, heart, liver, kidneys, etc. [3–5]. PET-CT imaging and more recently MRI-PET have been used to combine complementary diagnostic information from different imaging modalities into a single imaging device, removing the need for registration [6]. Using these scanning techniques, disease can be labeled and identified such that an earlier diagnosis with more accurate staging for patients may potentially be delivered [7].

Some of the statistics for the use of PET imaging in the U.S. is summarized in Fig. 1(a). Over 1,700,000 clinical PET and PET-CT studies were reported nation-wide for 2011 only. Compared to single PET imaging, the use of PET-CT is relatively higher and continuing to increase. PET imaging is mostly used for (i) diagnosis, (ii) staging, (iii) treatment planning, and (iv) therapy follow-up, in different fields of medicine such as (1) oncology, (2) cardiology, and (3) neurology (Fig. 1(b)). PET is widely used in staging and follow-up therapy in oncology applications (Fig. 1(c)). For instance, radiation therapy, as a common cancer treatment in oncology, aims to target the boundary and volume of abnormal tissue and irradiates the targeted area with a high dosage of radiation, intending to eliminate all cancerous cells. In practice, the determination of this boundary (i.e., delineation) should be kept as small as possible to minimize damage to healthy tissue, but the boundary must ensure the inclusion of the entire extent of the diseased tissue [2]. PET is also used in cardiac applications such as quantifying blood flow to the heart muscle and quantifying the effects of a myocardial infarction [8]. More recently, PET has been used for imaging inflammation and infection in the lungs [9] with ^{18}*F-FDG* because this glucose analog localizes to activated and proliferated inflammatory cells. The new norm in clinical practice is acquiring PET-CT images instead of a single PET scan to take advantage of the functional and structural information jointly.

In pre-clinical and clinical applications, physicians and researchers use PET imaging to determine *functional characterization* of the tissues. Owing to this, clinical trials are now placing a greater reliance on imaging to provide objective measures in before, during, and after treatment processes. The functional morphology (the area, volume, geometry, texture, etc.) as well as activity measures – such as standardized uptake value (*SUV*) of the tissues–are of particular interest in these processes. Accurately determining quantitative measures enables physicians to assess changes in lesion biology during and after treatment; hence, it allows physicians to better evaluate tumor perfusion, permeability, blood volume, and response to therapy. Among these measures, functional volume (i.e., the volume of high uptake regions) has been proven useful for the definition of target volumes [11]. Therefore, an accurate image segmentation method, other than the conventional region of interest (ROI) analysis, is often needed for diagnostic or prognostic assessment. This functional characterization has a higher potential for proper assessment due to recent advances in PET imaging. Indeed, this higher potential has renewed interest in developing much more accurate (even globally optimal) segmentation methods to turn hybrid imaging systems into diagnostic tools [11]. Specifically, after the adoption of multi-modal imaging systems (i.e., PET-CT, MRI-PET), optimal approaches for precise segmentation and quantification of metabolic activities were crucial.

For the literature search, we used Pubmed™, IEEEXplore™, Google Scholar™, and ScienceDirect™ and listed all the relevant articles from 1983 to March 2013. Our search also included the methods specifically developed for MRI and CT for comparison

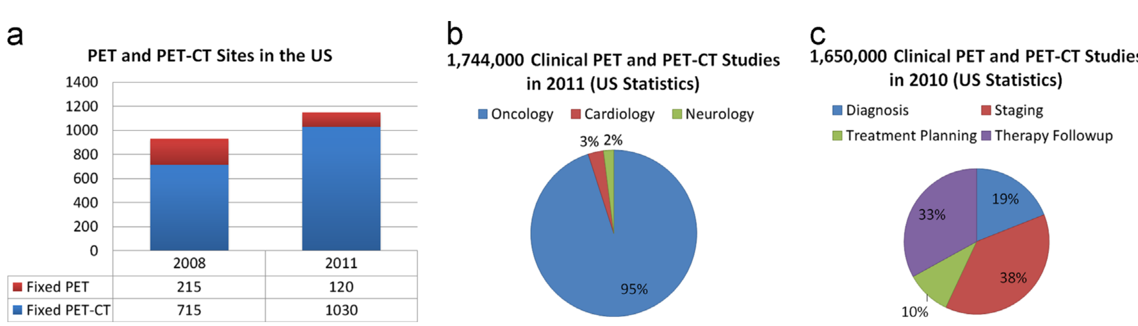

Fig. 1. A summary of PET technology used in the U.S is shown in (a) [10], (b) gives the breakdown of clinical PET and PET-CT studies in 2011 by the branch of medicine and (c) demonstrates 2010 PET technology used in the U.S. for oncology applications, in which PET has been used for mostly staging and follow-up therapy.

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