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Methodological Review

Symmetry and asymmetry analysis and its implications to computer-aided diagnosis: A review of the literature

Sheena Xin Liu

Department of Biomedical Informatics, Columbia University, New York, NY 10032, USA

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ABSTRACT

Although clinicians have long sought to integrate computer-aided diagnostic (CAD) systems into routine clinical practice, it has proven to be extremely difficult to perform fully automated algorithmic analyses on lesions, based solely on the information contained in images. To increase the utility of computerized tools, it would be intuitive to incorporate anatomical and pathological knowledge and heuristics to help the system draw diagnostic inferences. In neuro-imaging applications, for example, one way to perform this knowledge integration is to uncover symmetry/asymmetry information from the corresponding regions of the head and to explore its implication to positive clinical findings. To correctly quantify asymmetric patterns in brain images, however, the symmetry axis, or the symmetry plane, needs to be appropriately oriented in space; i.e., the symmetry plane needs to be correctly identified either manually or using computerized methods. This review will provide an overview of the current state of knowledge of both symmetry axis/plane detection, and asymmetry quantification in neuro-images.

1. Introduction

The advances in computer technologies, over the last decade or so, are catalyzing the development of modern computerized schemes for lesion detection in radiological images. One major challenge, however, is that computers generally lack sufficient perceptibility and intelligence in terms of discovering pathological patterns, which hinders the decision making process. Since it is known that anatomical knowledge plays an indispensable role in computer vision and artificial intelligence [1–3], integrating anatomical knowledge into the computer system holds great promise for facilitating decision making and improving patient care.

Based on the assumption that the brain exhibits a high level of bi-fold symmetry (Fig. 1) and that this symmetry is violated in the presence of pathological conditions, many researchers have been motivated to construct a symmetry-based paradigm for automatic localization and segmentation of brain lesions. The framework of this methodology is based on the hypothesis that the systematic correlation between asymmetry and pathologies can be a key to the improvement of existing detection algorithms. Integrating symmetry and asymmetry information as the prior knowledge or heuristics into a computer-aided diagnostic (CAD) [4–6] system, ought to enhance the system performance in the analysis of brain pathologies.

To correctly quantify asymmetric patterns in brain images, however, the symmetry axis, or the symmetry plane, needs to be appropriately oriented in space. This enables the system to correct the possible misalignment of radiological scans, and to evaluate hemisphere-wise asymmetry.

Therefore, this review paper has two main focuses. In the first part, the existing state-of-the-art methodologies for identifying the symmetry axis/plane of a given set of brain images will be investigated. In the second part, the discriminating capacity of symmetry/asymmetry in the context of extracting pathological findings in various radiological applications will be explored. In other words, to achieve the goal of using asymmetry as a pathologic index to assist CAD, we need to first solve an image registration problem, followed by a pattern recognition and segmentation problem. With respect to research significance and clinical significance, the ideas discussed in this paper, for a set of particular neuro-applications, might have much more general applicability for CAD in many other highly symmetrical parts of the human body, including the breasts and the limbs; more details can be found in Section 6.

2. Background

2.1. Computer-aided diagnostic system

Subjective, empirical assessment of medical images is generally performed manually by radiologists, which is a time consuming and tedious task. The outcome is usually operator-dependent. In the era of radiologists hanging and reading films on the alternators, the inspection of the scans was prone to errors owing to visual

E-mail address: xin.liu@dbmi.columbia.edu

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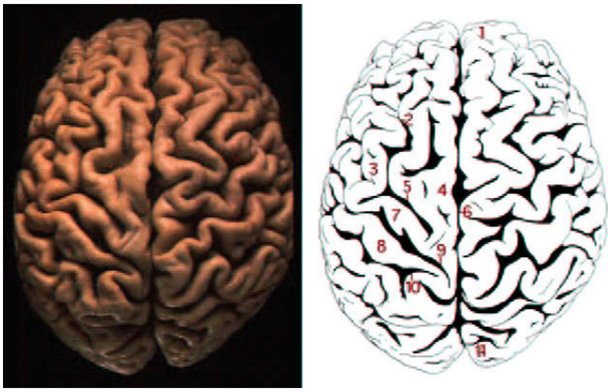

Fig. 1. The brain torque demonstrates that the brain is largely symmetrical, but not perfectly symmetrical: The right frontal lobe (1) is larger than the left one, and the left occipital lobe is larger than the right one (11). This illustration is adapted from [7].

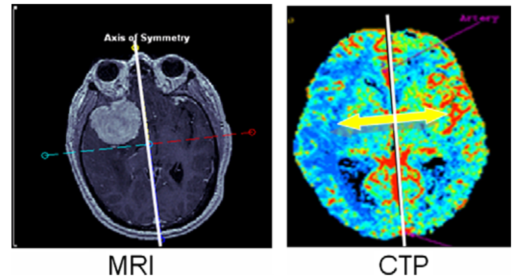

Fig. 2. Asymmetries exhibited in tilted image modalities such as magnetic resonance image (MRI) and CT perfusion images (CTP). When a clinician looks at those images, he or she consciously or subconsciously (1) identifies the symmetry axis/plane (2) compares the abnormality with the healthy side of the brain.

exhaustion after long hours of reading, or to limited experience of the radiologists.

Digital imaging has revolutionized the field of medical imaging and has led to the development of sophisticated computer hardware technologies (e.g., data storage, transmission [8] and display [9]), and specialized software (e.g., registration tools [10] and expert systems [11,12]) that empower physicians to better distinguish abnormalities, characterize findings, supervise interventions, and predict prognosis. The advances in the hardware, in particular, over the last decade or so, are catalyzing the development of modern computerized schemes for lesion detections in radiological images. These techniques and methods, collectively called computer-aided diagnosis (CAD), are bringing about a new era in which computers are assisting a wide spectrum of applications in medical domains. In fact, CAD has become one of the major research subjects in medical imaging and diagnostic radiology [4].

With respect to software, although clinicians have long sought to integrate CAD systems into routine clinical practice, a readily usable software system that can efficiently characterize lesions is still a rarity even in major research hospitals. It has seemed to be extremely difficult to perform an algorithmic image analysis on lesions, given the limitations of available intelligence systems. To empower the computerized systems, it would seem intuitive to incorporate knowledge and heuristics of disciplines such as anatomy and pathology, to help the system draw diagnostic inferences. One strategy for development of techniques for lesion detection is based on understanding the process of radiologists assessing images—such as how radiologists can discover lesions, why they may miss some abnormalities, and how they can distinguish between benign and malignant lesions [13].

2.2. Brain abnormality detection

Brain images of a variety of modalities can disclose anatomical (MR, CT), functional (PET, SPECT), or physiological (CTP, MRP) information that is crucial to the diagnosis and treatment of patients (Fig. 2). Automated detection and segmentation of brain abnormalities spans several decades of research, and still remains a challenging problem. To facilitate fully automated segmentation, it is known that image information alone is insufficient [14] to successfully differentiate between target organs, abnormal tissue, and the background. For example, statistical classification methods may fail when a brain lesion shows insufficient contrast against its background, or presents highly inhomogeneous patterns.

On the other hand, in medical images of most state-of-the-art modalities, absolute values only provide a reference in terms of dissecting pathologies. The inter-individual and inter-equipment variations, even under controlled settings, are often so high that it is impossible to directly draw inferences upon the absolute values. Finding statistically significant *relative* values may provide more insights for detecting and quantifying brain abnormalities in computerized analysis.

One way to examine the relative values, particularly in brain images, is to uncover symmetry/asymmetry information from the corresponding regions of the head, and to explore its implications with respect to positive clinical findings (see Fig. 2). The hope is that, with the integration of this information into classification algorithms, a more knowledge-driven and potentially successful diagnostic interpreter can be created.

2.3. Neuro-images: misalignment in clinical settings

A common phenomenon in radiological scanning is that many neuro-imaging devices produce disoriented brain images; the scanned brain images are somewhat tilted and distorted [15]. Tilt and distortion can mislead visual inspection, and often yield false clinical interpretation, since slices of the brain images are no longer representing homologous structures within the same coronal or axial level [7]. The tilt of the head is often observed in the device during the scanning process, however, is not always tractable. Common reasons include, but are not limited to, immobility of patients, inexperience of the technicians, and imprecision of calibration systems [16].

Correcting the tilt of the head is equivalent to realigning the mid-sagittal plane (MSP) with the center of the image lattice. The MSP is defined as the plane that best separates the brain into two halves [7]. It is evident that the re-adjustment of the MSP from the geometrical misrepresentation yields more sensible data assessment either by a human expert or a computer program that is based upon hemisphere-wise cross referencing.

2.4. Symmetry and its clinical implications

Morphologically speaking, a normal human head exhibits a high level of bilateral symmetry, although it is not perfectly symmetrical [17]. Corresponding regions of two hemispheres have approximately identical anatomical properties, and also have comparable, if not identical, physiologic (e.g., blood perfusion) properties. The degree of asymmetry has long been thought to be helpful for suggesting a pathological condition and/or providing a diagnostic cue for clinicians. For example, abnormal asymmetry in the brain indicates a wide range of pathologies, such as stroke, bleeding and tumor. Radiologists routinely use symmetry/asymmetry as one of the most discriminating features, in conjunction with other characters such as location, neighborhood relationship, and shape, to assess abnormalities in brain images.