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Medical image analysis for cancer management in natural computing framework

Sushmita Mitra *, B. Uma Shankar

Machine Intelligence Unit, Indian Statistical Institute, Kolkata 700108, India

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ABSTRACT

Natural computing, through its repertoire of nature-inspired strategies, is playing a major role in the development of intelligent decision-making systems. The objective is to provide flexible, application-oriented solutions to current medical image analysis problems. It encompasses fuzzy sets, neural networks, genetic algorithms, rough sets, swarm intelligence, and a host of other paradigms, mimicking biological and physical processes from nature.

Radiographic imaging modalities, like computed tomography (CT), positron emission tomography (PET), and magnetic resonance imaging (MRI), help in providing improved diagnosis, prognosis and treatment planning for cancer. This survey highlights the role of natural computing, in efficiently analyzing radiographic medical images, for improved tumor management. We also provide a categorization of the segmentation, feature extraction and selection methods, based on different natural computing technologies, with reference to the application – involving malignancy of the brain, breast, prostate, skin, lung, and liver.

1. Introduction

Medical image analysis encompasses the study of both anatomy (or structure) and the function of the tissues under consideration. It includes image segmentation, feature extraction, classification, image matching/registration, motion tracking, change detection from image sequences, and the measurement of anatomical as well as physiological parameters from images [1]. Research in these areas strives to provide improved solutions to image-guided surgery/intervention, atlas-based description of entire anatomical regions, deformation analysis based on biomechanical and other models, and visualization of anatomical and physiological processes.

Over the last decade cancer has become the deadliest killer worldwide. There has also been a significant growth in cancer cases within the developing world. Typically cancer causes cells to proliferate in an uncontrolled manner, thereby spreading throughout the body. *Carcinomas*, which account for about 90% of all cancers, arise from the epithelial cells that cover external and internal body surfaces. Lung, breast, and colon cancer are the most frequent of this type. *Sarcomas*, another common form of cancer, develop from the cells of supporting tissues such as bone, cartilage, fat, connective tissue, and muscle. *Lymphomas* and *leukemia* arise from cells of blood and lymphatic origin, and constitute another major type of cancer.

* Corresponding author.
E-mail addresses: sushmita@isical.ac.in (S. Mitra), uma@isical.ac.in (B. Uma Shankar).

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Surgery is often chosen for the treatment at the early stage of many types of cancer. However, since most detections happen at an advanced stage, often a combination of chemotherapy and radiotherapy is selected as the treatment modality. It is observed that distant metastasis[1] and failure of local tumor control result in such poor patient prognosis. Therefore, new investigations are required for improved tumor control [2].

Quantitative imaging, using current radiographic modalities like computed tomography (CT), magnetic resonance imaging (MRI) and positron emission tomography (PET), is playing an increasingly important role in the design of oncology trials addressing molecularly targeted personalized therapies [3,4], involving patient prognosis, outcome prediction, response to therapy, surveillance after treatment, and research. Radiomics is defined as the high-throughput automated (or semi-automated) extraction of large amounts of quantifiable information (or image features) from radiographic images for an improved management of the disease (or tumor) [5,6]. The challenge is to integrate diverse, multimodal information in a quantitative manner to provide specific clinical predictions for accurately and robustly estimating patient outcomes towards the design of clinical decision-support systems. Medical image fusion is the process of registering and combining multiple images from single or multiple imaging modalities, in order to improve the imaging quality and reduce randomness and redundancy, towards increasing the applicability of medical images for improved diagnosis and assessment of medical problems [7].

1.1. Need for automated image analysis

The complete medical evaluation of a patient usually requires a thorough history and physical examination along with diagnostic testing, particularly to confirm presence or absence of the disease and estimate its prognosis. Diagnostic procedures for cancer include imaging, laboratory tests, tumor biopsy, endoscopic examinations, surgery, or genetic testing. Imaging is the process of visualizing body structures and organs in order to determine the extent of the disease (staging), evaluate the effectiveness of the treatment, and guide the precise deliverance of various tumor-destroying approaches, like radiation and surgical procedures.

Identifying specific organs or other features in medical images requires considerable expertise concerning the shapes and locations of the anatomical features. Image segmentation and detection, of such different regions or volumes of interest (ROI or VOI), is typically performed manually by expert physicians as part of treatment planning and diagnosis. However due to the increasing amount of available data and the complexity of the features of interest, it is becoming essential to develop automated delineations to assist and speedup image understanding. Besides, the existence of inter-observer, inter-patient and inter-scanner variability, coupled with relatively low spatial resolution, make computer-guided delineations (based on objective criteria) desirable for outlining the tumor boundary. Computer-based quantitative image analysis is thus becoming an important field, with an increasing reliance on it by the biomedical community.

Many of the biologic aberrations of cancer can be imaged *in vivo*[2] with none or minimal tissue disruption. Functional imaging techniques can depict these processes at the tumor level, in peritumoral regions, and at the organ as well as organism levels. (i) Anatomic measurements like tumor size, tumor mass, tumor volume, cellular density, and lesion regression rates, (ii) attributes like computed tomography (CT) attenuation (in Hounsfield units) measurements, along with (iii) functional parameters like altered vascularity or metabolism within tumors, changes in contrast enhancement and tissue diffusivity, have been found to be useful in cancer management. Biomarkers[3] provide unique information on tumor behavior and its response to treatment. Today imaging biomarkers are beginning to play a major role in the drug development process.

Imaging, thus, encompasses the automated analysis of medical images from different imaging modalities, including pattern recognition strategies like clustering (or segmentation), feature extraction from the segmented region of interest, feature analysis, and decision-making, within an interdisciplinary framework involving mathematicians, medical experts and computer scientists. Segmentation is a fundamental process in medical research and clinical applications, including quantification of tissue volume, diagnosis of illness, computer-guided surgery, treatment planning, surgical simulation, therapy evaluation, functional mapping, and study of anatomical structures. Feature analysis leads to dimensionality reduction, with resultant algorithms having lower computational complexity. Finally decision-making is related to patient prognosis and survival analysis.

Multiparametric imaging [8] aims to combine the information from different functional imaging techniques, thereby managing to surpass the capability of any single type of imaging and allowing an improved understanding of biological processes along with their responses to therapeutic interventions. The last two decades have witnessed many technological advances in the development of three-dimensional treatment planning systems and image-guided methods to improve tumor localization while sparing surrounding normal tissues [8,9].

1.2. Role of natural computing

Natural computing [10], inspired by nature and biological systems, is an interdisciplinary field that (i) formalizes natural processes observed in living organisms to develop computational methods for solving complex problems, (ii) designs

[1] The spread of a cancer from one organ or part to another non-adjacent organ or part.
[2] Experimentation using a whole living organism, as opposed to a partial or dead organism.
[3] Indicator of a biological state, in response to the introduction of a traceable substance in an organism for examining organ function or other aspects of health.