Medical Imaging: A Review

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Abstract. The rapid progress of medical science and the invention of various medicines have benefited mankind and the whole civilization. Modern science also has been doing wonders in the surgical field. But, the proper and correct diagnosis of diseases is the primary necessity before the treatment. The more sophisticate the bio-instruments are, better diagnosis will be possible. The medical images plays an important role in clinical diagnosis and therapy of doctor and teaching and researching etc. Medical imaging is often thought of as a way to represent anatomical structures of the body with the help of X-ray computed tomography and magnetic resonance imaging. But often it is more useful for physiologic function rather than anatomy. With the growth of computer and image technology medical imaging has greatly influenced medical field. As the quality of medical imaging affects diagnosis the medical image processing has become a hotspot and the clinical applications wanting to store and retrieve images for future purpose needs some convenient process to store those images in details. This paper is a tutorial review of the medical image processing and repository techniques appeared in the literature.

Keywords: bio-instruments, tomography, magnetic resonance, physiologic, anatomy, clinical.

1 Introduction

Medical imaging refers to the techniques and processes used to create images of the human body (or parts thereof) for various clinical purposes such as medical procedures and diagnosis or medical science including the study of normal anatomy and function. In the wider sense, it is a part of biological imaging and incorporates radiology, endoscope, thermograph, medical photography, and microscopy. Measurement and recording techniques such as electroencephalography (EEG) and magneto encephalography (MEG) are not primarily designed to produce images but which produce data susceptible to be represented as maps, can be seen as forms of medical imaging.

In the clinical context, medical imaging is generally equated to radiology or "clinical imaging". Research into the application and interpretation of medical images is usually the preserve of radiology and the medical sub-discipline relevant to medical

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condition or area of medical science (neuroscience, cardiology, psychiatry, psychology) under investigation. Many of the techniques developed for medical imaging also have scientific and industrial applications.

Although the mathematical sciences were used in a general way for image processing, they were of little importance in bio-medical work until the development of computed tomography (CT) for the imaging of X-rays (leading to computer-assisted tomography or CAT) and isotope emission tomography (leading to Positron Emission Tomography or PET scans and single Positron Emission Computed Tomography or SPECT scans), then MRI (magnetic resonance imaging) ruled over the other modalities in many ways as the most informative medical imaging methodology [1].

Besides all these well established techniques computer based methods are being explored in application of ultrasound and electroencephalography as well as new techniques of optical imaging, impedance tomography and magnetic source imaging. Though the final images obtained from many techniques have similarities but the technologies used and the parameters represented in the images are very different in characteristics as well as in medical usefulness, even different mathematical and statistical models have been used.

Several techniques have been developed to enable CT, MRI and ultrasound scanning software to produce 3D images for the physician. Traditionally CT and MRI scans produced 2D static output on film then to produce 3D images many scans are made and then produced a 3D model which can be manipulated by physician [2].

In this paper, we have tried to present a detail survey on Medical Imaging and we hope that this work will definitely provide a concrete overview on the past, present and future aspects in this field.

2 Overview

Medical imaging is considered as a part of biological imaging, which has been developed from 19^{th} century onwards. A brief overview of medical imaging is as follows [3]:

In 1895 Roentgen accidentally discovered X-rays. Conventional radiography has been the most widespread medical imaging technique ever science. From 1896 radio-nuclides were for therapy and for metabolic tracer studies rather than imaging. Then γ- ray imaging rectilinear scanner was invented.

During World War 2 Sonar Technology and in 1970's ultrasound became widely available in medicine.

In 20^{th} century the mathematical principles behind tomographic reconstruction have been understood and positron emission tomography (PET) and X-ray computed tomography (CT) have been developed. Nuclear magnetic resonance has been using for imaging in magnetic resonance imaging (MRI).

In 21^{st} century X-rays, MRI, ultrasound kept dominating but more interesting techniques especially imaging is getting included with microscopic as well as macroscopic biological structures (thermal imaging, electrical impedance tomography, scanned probe techniques etc).

In future the emphasis will be increased on obtaining functional and metabolic information along with structural (image) information. This can be done to some extent with radioactive tracers (e.g. PET) and magnetic resonance spectroscopy [4].

3 Techniques and Applications

Advances in image technology; visualization technology and graphics workstation has initiated many different processes and ways of medical imaging. Among which the application of wavelet transform in medical images, segmentation of medical images, virtual medical imaging subsystems are of paramount importance.

⇒ *Medical image creation and capture techniques:*

A. *Application of Wavelet Transform Technology:*

The wavelet technology is widely applied to the domain of medical imaging and wavelet transform and inverse transform algorithms are introduced. Wavelet technology has been used in ECG signal processing, EEG signal processing, medical image compression, medical image reinforcing and edge detection, and medical image register.

- *Wavelet Transform:*

Wavelet families of functions generated from base function $\Psi(t)$, called an analyzing wavelet or mother wavelet.

$$\Psi a,\tau(t) = 1/\sqrt{a}\ \Psi((t-\tau) / a) \quad a>0.$$

Where $\Psi(t)$ satisfies $\int \Psi(t)\, dt = 0$

a=scale parameter

τ = Translation parameter.

The wavelet transform has features of multi-resolution or multi scale. The scaling operation is just “stretching” and “compressing” operation. We restrict ourselves in binary scaling and use discrete wavelet transform (DWT) [5].

- *2D wavelet and inversion transform:*

The image can be expanded in terms of the 2D wavelets. At each stage of the transform, the image is decomposed into 4-quarter size images. For an N-by-N image, the image is decomposed into four N/2-by-N/2 images for that stage of the transform.

1. *Application of wavelet transform in ECG signal processing:*

As it is known, QRS complex, P waves and T waves of ECG contains plenty of information of human heart. The method of QRS waves detector ago mainly contain differential threshold method, slope method, areas method etc., but these has more e. m. r rate in the condition of seriously interference. Bradie [6] propose wavelet packet-based compression of signal lead ECG. Zheng Kaimei [7] proposed semi-loss less compression algorithm of ECG signal based on WT.

2. *Application of wavelet transform in EEG signal processing:*

The EEG signal is the mainly bases for the analysis of disease and symptom in neural system especially epilepsy. Kalayic [8] detect EEG spikes by using wavelet transform. Zhou Weidong [9] study the EEG signal singularity detection and denoising methods based on the dyadic WT modulus maxima, and the de-noising method can remove noise effectively as well as keep original EEG singularity.

3. Applications of wavelet transform in medical image processing:

Image Compression:

To meet the demand for high-speed transmission of image in efficient image storage and remote treatment, the efficient image compression is essential. Recently some new and very promising method emerges in the field of image compression algorithm based on WT, such as wavelet packet transform [10-11].

A.S.Tolba [12] discovers the hest design parameters for a data compression scheme applied to medical images of different imaging modalities. The proposed technique aims at reducing the transmission cost while preserving the diagnostic integrity.

Reinforcing medical image & edge detection:

According to the properties of its multi-scale, direction and local characteristic, determining the local maxima of wavelet coefficients provided the image edge features. Medical image enhancement and edge detection are very important in breast image.

Yuan ye [13] proposed a method of edge detection based on WT and fuzzy algorithm.

Register medical image:

Medical image registration is a pre-processing step in object identification and object classification.

Raj Sharman [14] et al. presents a fast, accurate, and automatic method to register medical image using Wavelet Modulus Maxima. It uses wavelets to obtain control points.

Several main aspects need further development study on its foundation theories and methods; the choice method of the best wavelet base; multi wavelet theory and its application; application of combined wavelet transform with neural network, application of combination of fractal and wavelet etc.

B. Segmentation of medical images (using LEGION method):

Computer vision literature typically identifies three processing stages before object recognition: image enhancement, feature extraction, and grouping of similar features. The last step, image segmentation, where pixels are grouped into regions based on image features, is an important feature, which we would discuss. The goal is to partition an image into pixel regions that together represent objects in the scene.

A recently proposed oscillator network called the locally excitatory globally inhibitory oscillator network (LEGION) whose ability to achieve fast synchrony with local excitation and desynchrony with global inhibition makes it an effective computational framework for grouping similar features and segregating dissimilar ones in an image. Using algorithms of LEGION dynamics and as results of the algorithm to two-dimensional (2-D) and three dimensional (3-D) (volume) computerized topography (CT) and magnetic resonance imaging (MRI) medical-image datasets.

• *LEGION model:*

LEGION was proposed by Terman and Wang [15, 16, 17], [32] as a biologically plausible computational framework for image analysis and has been used successfully to *segment binary and gray-level images* [33]. It is a network of relaxation oscillators, each constructed from an excitatory unit and an inhibitory unit. 2-D network architecture with four-neighborhood coupling is also used here. The global inhibitor, usually represented with a black circle, is coupled with the entire network.

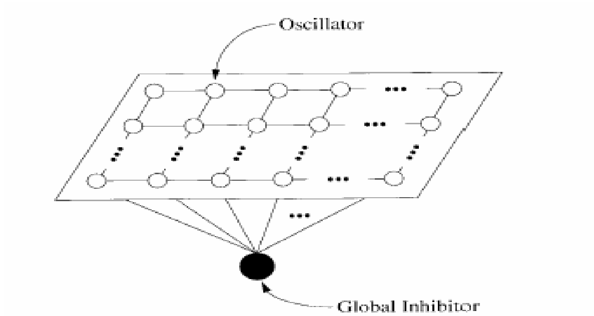

Fig. 1. A 2-D LEGION network with four-neighborhood connections

• *Segmentation algorithm:*

There are *three intuitive criteria* for defining segments (groups) on an image. The first is that leaders should be generated from both homogeneous and brighter parts of the image. Second, brighter pixels should be considered similar to wider ranges of pixels than darker ones. The third criterion stipulates that the boundaries of segments are given where pixel intensities have relatively large variations. For Three-dimensional segmentation is readily obtained by using 3-D neighborhood kernels.

Here the segmentation algorithm has been used on 2-D and volume CT and MRI medical datasets of the human head. The user provides six input parameters: the potential neighborhood; the recruiting neighborhood; the threshold; the power of the adaptive-tolerance-mapping function; and the tolerance range-variables.

(a) (b)

Fig. 2. Segmentation of a 256 _ 256 MRI image. (a) Original gray-level image of a human head. (b) A gray map showing the result of segmentation.

LEGION network, besides its biological plausibility, is especially feasible for parallel-hardware implementation, which would be important for real-time segmentation of volume datasets. *Manual segmentation* generally gives the best and most reliable results when identifying structures for a particular clinical task.

One objective of medical-image segmentation is to separate *white matter and gray matter*. This algorithm is intended to be more flexible for segmenting a variety of structures. However, it is interesting to note that once the brain is segmented, this algorithm in another pass can perform the separation of gray matter from white matter [18].

Layers of LEGION networks are effective computational framework that is capable of grouping and segregation based on partial results from preceding layers, and thus may further enhance segmentation performance. The network architecture is amenable to VLSI chip implementation, which would make LEGION a plausible architecture for real-time segmentation.

C. Superimposing a medical image within the subject:

For superimposition of medical image, within the subject itself, a virtual medical imaging system has been used in which 3-dimensional (3D), stereoscopic, motion (if necessary) medical image is superimposed within the subject via a see-through head mounted display [19]. For displaying more realistically, the 2D images are reconstructed in 3D images using computer graphics and for stereographic views a head mounted display providing separate images for each eye is useful. Virtual reality has been popular in representing data obtained using medical imaging devices much as echography, MRI, CT.

The medical imaging system consists of 3 subsystems: geometric information I/O, 3D object generations and image merging subsystem.

The geometric information I/O subsystem consists of polhemus receivers and polhemus transmitter. The see-through head-mounted display, shimadzu STV-E is also used.

The system is applied to echocardiogram. The original echo images in the 3D object generation subsystem was obtained by measuring 28 successive B-mode echo images of the heart, using a sector scanning Tran esophageal probe.

When the virtual imaging system was applied to echocardiogram, the virtual heart image changed its size, orientation and binocular parallax approximate for both the observer and the subject. The problem that the echo image was just pasted one onto the subject was somewhat improved in this system due to the stereographic image having reality along depth direction. This virtual medical imaging system will be beneficial to clinics for purposes such as surgical planning in the near future.

⇒ *Medical image repository and image categorization:*

In the last decade medical imaging has become an essential component of medical field. Moreover, the development of the Internet has made medical images available in large numbers in online repositories, atlases and other heath-related resources. These images represent a valuable source of knowledge and have significant importance for medical information retrieval. Medical image repository plays an important role in the hospital workflow. The operations in the hospital workflow such as image storage and retrieval, viewing, post processing can be saved as a generic repository component using which different modalities can develop their own clinical application.

A. COTS-Like Generic Medical Image Repository:

Commercial off-the-shelf software (COTS) is used for storage and retrieval of medical image data with the underlying storage being a commercial RDBMS. A generic medical image repository capable of serving multiple modalities can be treated similar to a COTS component.

The phrase "Medical Image Repository" is being used to describe a generic storage component consisting of a Data Access Layer (DAL) [20]. Clinical applications wanting to store and retrieve images use this storage component. Here in ref. [20] an innovative approach of how one single generic medical image repository subsystem (where the components satisfy characteristics of COTS product) can allow various modalities, viewing, work stations and PACS (Picture Archiving and Communications System) to perform 'store', 'view', 'query' operations have been explained. It also explains how this enables generic applications like basic viewing and printing of images to be reused across modalities and workstations.

The process for COTS software product evaluation [21] defines a COTS product as one that is:

a. Supported and evolved by the vendor, who retains the intellectual property rights.
b. Available in multiple, identical copies.
c. Used without modification of the internals.
d. Offered by a vendor trying to profit from it.
e. Sold, leased, or licensed to the public.

The medical image repository component described in ref. [20] satisfies all of the above except for (d) and (e) as only various product groups (modalities). Hence, it can be referred to as a COTS-like product.

In addition to the above-mentioned criteria [22] also talks of other criteria that are typically present in any COTS-like component. These criteria include:

- Interoperability: It defines Information Objects, which are abstractions of real information entities such as CT Image, MR Image etc.
- Diversity in requirements: A generic medical image repository must satisfy the following criteria:
  - Support for multiple modalities.
  - Different information models.
- Flexibility
- Usability
- Performance
- Reliability
- Portability

There was an assumption that generic repository means a trade-off between maintenance and performance. With the emergence of this COTS-like repository, this assumption has been proven to be a myth. Places, where the modalities as well as the PACS are from the same vendors, the generic repository component can be deployed in a client/server model, thereby giving a provision for an efficient proprietary protocol instead of DICOM.

B. Medical image categorization using a texture based symbolic description:

In the field of medical image indexation, automatic categorization provides the means for extracting, otherwise unavailable, information from images.

The content-based automatic medical image categorization methods, in the on-line context of the CISMeF health-catalogue are focused in ref. [23]. The compact symbolic image representation conveys enough of the initial texture information to obtain high recognition rates, despite the complex context of multimodal medical image categorization.

Medical image categorization architecture, based on a new type of image descriptor, aiming to accurately extract the modality (e.g. MRI, XRay1), and the anatomical region present in medical images.

When publishing (e.g. on the Internet) the images are suffering further transformations resizing, cropping, high-compression, superposed didactical drawings and annotations. Thus the image variability (already significant due to anatomical and pathological differences) is increased. The strong inter-class similarity between some classes (representing different modalities and anatomical regions) further increases difficulty in categorization.

The categorization approach consists of three stages:

1) The extraction of statistical and texture image-feature sets to describe the image visual content: Each image is represented by a vector of 16 blocks, and from each block features will be extracted to describe its content.
2) The description of these features using a symbolical representation: CLARA (Clustering Large Applications) [22], AGNES (Agglomerative Nesting) [24] are used respectively for clustering.
3) The classification of the description vectors into the defined classes: A k-Nearest Neighbor classifier is employed, using the first (INN), the first three (3NN) and the first five (5NN) neighbors (weighted by distance). For computing distances between nominal representations VDM (i.e. Value Difference Metric) is used, a metric introduced by ref. [25] to evaluate the similarity between symbolic (nominal) features.

The suggested feature representation/transformation method is close to Vector Quantification (VQ) where the blocks of pixels are labeled with the indexes of the prototype blocks [26]. The fixed block split, here used in ref. [23], is considered necessary to take into account the spatial distribution of the texture and statistical features. Unfortunately this approach is more sensitive to image rotations and translations. However, given that the modern digital acquisition equipments are following standard acquisition procedures, the images are rarely presenting significant variations to rotation and/or translation.

C. Web-based interactive applications of high-resolution 3D medical image data:

The demands for sharing medical image data on the Internet for computerized visualization and analysis are growing consistently such data sizes (ranging from several hundred megabytes to several dozen gigabytes [27,28]) severely stress storage systems and networks, and present many challenges in development of Web-based interactive applications.

Because of the limits imposed by the available bandwidth of the Internet, Web-based interactive applications are limited to low- or medium-resolution image data [29,30], which are often insufficient for reliable use in clinical diagnosis.

Gustafson et al. have developed a software package (stand alone system [32, 27, 31, 28]), named MACOSTAT, for assembly and browsing of 3D brain atlases [31].

A novel framework for Web-based interactive applications of high-resolution 3D medical image data has been proposed in ref. [33]. Specifically, first partition the 3D data into buckets, and then compress each bucket separately. Also an indexing structure for these buckets to efficiently support typical queries such as 3D slicer and region of interest (ROI), and only the relevant buckets are transmitted instead of the whole high resolution 3D medical image data.

The proposed framework in ref. [33] (see Figure 3) consists of three major components: *data storage structure, disk access optimization,* and *server query processing*.

◊ *Data storage structure:*

1) Partitioning the whole high-resolution 3D image data into buckets.
2) Each data bucket is a small subset of the whole 3D image data set and can be compressed/decompressed using any existing loss less or lossy compression technique [34, 27, 35], depending on the given application.
3) To facilitate disk access optimization, disk space is allocated to the data buckets in Hilbert curve order. Hilbert curve [36, 37] is a space filling technique, which maps a multi-dimensional data space into a one-dimensional data space; that is, it defines a linear order to visit every data bucket in the three-dimensional space exactly once.

◊ *Data access optimization:*

To reduce the demand on server in terms of disk access and communication costs, we use two techniques.

- Incremental transmission:

A client can send some bucket IDs along with a query to inform the server that those buckets are available locally and are not necessary to be retransmitted.

- Group Access:

In a multi-user environment, instead of retrieving data buckets for each of the queries independently, we allow them to share disk access by retrieving the data buckets inside the MBB which encloses all the ROI's, in one sequential access.

◊ *Server Query Processing:*

For ROI queries, first the MBB of the ROI is determined and then process the corresponding range query using the octree to identify the relevant data buckets that overlap with the MBB.

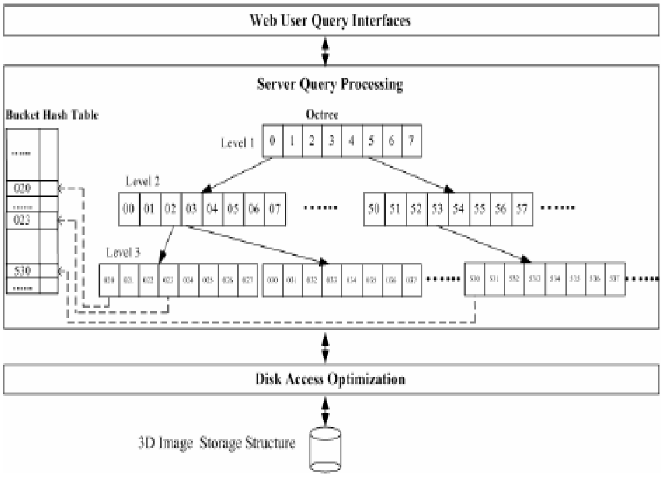

Fig. 3. An overview of the proposed framework

The problem of developing Web-based interactive applications of high-resolution 3D medical image data enables real-time interaction with remote high-resolution 3D medical images. This is achieved with the scalability to allow many concurrent users to receive the service simultaneously.

4 Discussion

So far we have seen various methods of medical image processing and the way of getting 3-dimensional images. In the wavelet technology for high-speed transmission of images efficient compression scheme is essential. Further development can be done in various aspects multi-wavelet theory and its application, application of combined wavelet transform with neural network, application of combination of fractal and wavelet etc.

Segmentation is a very difficult problem for general images, which may contain effects such as highlights, shadows, transparency, and object occlusion. On the other hand, sampled image datasets lack these effects with a few exceptions. Three broad classes that divide algorithms to segment sampled image data: are manual, semiautomatic, and automatic. The LEGION approach is able to segment volume datasets with appropriate parameter settings; produces results that are comparable to commonly used manual segmentation.

Other tolerance functions may also be used to better define pixel similarity.

For viewing the images more realistically, 3D representation is necessary, so a virtual imaging subsystem using a see-through head mounted system was used. It is beneficial for clinical purpose.

Generic medical image repository components catering all the important characteristics of the COTS like software products have been develop. Further, it has now spread its wing beyond the medical imaging repository and is now being used as a log repository and configuration repository.

High-resolution three-dimensional (3D) medical image data have become increasingly common with the advances and wide availability of medical image acquisition technologies.

Most existing Web-based 3D medical image interactive applications therefore deal with only low- or medium-resolution image data. But it is possible to download the whole 3D high-resolution image data from the server. An indexing structure for data buckets to efficiently support typical queries such as 3D slicer and region of interest (ROI), and only the relevant buckets are transmitted instead of the whole high resolution 3D medical image data. The study based on a human brain MRI data set indicates that the proposed framework can significantly reduce storage and communication requirements, and can enable real-time interaction with remote high resolution 3D medical image data for many concurrent users.

5 Conclusion

Biomedical imaging has seen truly exciting advances in recent years. Newly invented imaging methods can now reflect internal anatomy and dynamic body functions heretofore only derived from textbook pictures, and applications to a wide range of diagnostic and therapeutic procedures can be possible. Not only improvement in computer technology, but development will require continued research in physics and the mathematical sciences (e.g., artificial intelligence), fields that have contributed greatly to biomedical imaging and will keep continuing to do so.

The major topics of recent interest in the area of functional imaging involve the use of MRI and positron emission tomography (PET) to explore the activity of the brain when it is challenged with sensory stimulation or mental processing tasks. The emerging imaging methods have the potential to help major medical and societal problems, including the mental disorders of depression, schizophrenia, and Alzheimer's disease and metabolic disorders such as osteoporosis and atherosclerosis.

Although computing speed certainly has reached the point where iterative methods are clinically feasible for 2D problems, the focus is now on 3D PET where the size of A is 11-15 times larger than in 2D (after exploiting symmetries). Thus there is continuing need for new ideas in image reconstruction algorithm development.

Finally, it is worth mentioning, the explosion in the use and utility if the Internet including some resources of specific interest to the medical imaging community. The World Wide Web offers a great platform for education and teaching and has become the major method of sharing and communicating medical information. The creation of "digital departments" [38, 39] provides access to multimedia reporting (text, images, cines) from inexpensive client systems. Further, the WWW will allow use of Java applets to provide additional functionality such as analysis, to be implemented on Java compliant browsers.

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