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Multimodal Imaging and Its Application in Medical Science

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***Abstract:** Medical imaging is a process of collecting information about a specific physiological structure (an organ or tissue) using a predefined characteristic property that is displayed in the form of an image. For example, in X-ray radiography, mammography and computed tomography (CT), tissue density is the characteristic property that is displayed in images to show anatomical structures. The information about tissue density of anatomical structures is obtained by measuring attenuation to X-ray energy when it is transmitted through the body. On the other hand, a nuclear medicine positron emission tomography (PET) image may show glucose metabolism information in the tissue or organ. A PET image is obtained by measuring gamma-ray emission from the body when a radioactive pharmaceutical material, such as flurodeoxy glucose is injected in the body. This technology is helping biochemists, biologists, medical scientists, and physicians to obtain quantitative measurements, which facilitate the validation of scientific hypothesis and accurate medical diagnosis. Images of human organs such as the heart, breast, lung, and brain, play an important role in diagnostic radiology, psychiatry, cardiology, and internal medicine.*

***Keywords:** Medical imaging, CT,X-Ray, PET, Mammography, diagnosis*

I. INTRODUCTION

Most of the attributes of digital images and the methods of image processing introduced from outside of medicine. We can single out medical imaging for special consideration because the lives of people often depend on correct acquisition, processing, and interpretation of medical images. It is important that individuals responsible for acquiring and processing medical images understand both the nature of the raw material they work with, and the way the images they produce will be used. Those using medical images for research, rather than purely clinical purposes, also need to understand the way their raw data is acquired to ensure the scientific rigor of their work.

The purpose of medical imaging is to reveal and record the *structural* or *functional* state of the body. Mostly we want to see what is going on inside the body – to check that all is well, or to find out why all is not well. Sometimes we want a record of the current state of the body to be referred to at some future time – to monitor the progress, or absence of progress, of a disease or a treatment. The majority of medical images are intended to reveal aspects of the body that cannot be observed by visual inspection or physical examination of the exterior of the body. Interestingly, most medical imaging methods produce a visible light image that *represents* a physical property of body tissue which *cannot* be observed with visible light – at least not without resorting to surgery, which is mostly expensive and possibly counterproductive. We know from years of development of medical imaging modalities[6] that certain measured physical phenomena correlate with biological properties of interest – either disease or normal structure and function. The correlation between physics and biology is easy to understand in the case of something like X-ray imaging – we expect the transmission of X-rays to reveal the structure and arrangement of bones because the method we use to acquire the image is so similar to our everyday experience of light and shadows. At the opposite end of the spectrum of expectation we find methods such as functional MRI in which we infer altered neural activity by measuring the differential relaxation of an induced nuclear magnetic resonance signal. For fMRI the steps between the investigated biological phenomenon and the observed signal are numerous: increased neural activity – local depletion of oxygen tension – increased blood flow – increased local oxyhaemoglobin concentration – diamagnetic alteration of spin relaxation rate; and all of this changing on a time scale of seconds. The demands on image processing and the potential for artifacts are considerable. A user of the technology who is unaware of it's assumptions and limitations is likely to misinterpret the images produced.

II. MULTIMODAL MEDICAL IMAGING SYSTEM

Medical imaging[6, 7] deals with the interaction of all forms of radiation with tissue and the design of technical systems to extract clinically relevant information, which is then represented in image format. Medical images range from the simplest such as a chest X-ray to sophisticated images displaying temporal phenomena such as the functional magnetic resonance imaging (fMRI)[6].

There are several imaging modalities that can be applied to obtain more detailed information of an abnormality. For example, in diagnostic radiology four different media can be used. This is illustrated in Table 1 where US means ultrasound and MR means magnetic resonance.

X-rays	Breast, lung, bone
γ-rays	Brain, organ pgirenchyma, heart function
MRI	Soft tissue, disks, brain
US	Fetus, pathological changes, internal organs

TABLE 1 Range of application of the most important radiologic imaging modalities.

Medical imaging involves a good understanding of imaging medium and object, physics of imaging, instrumentation, and often computerized reconstruction and visual display methods. Though there are a number of medical imaging modalities available today involving ionized radiation, nuclear medicine, magnetic resonance, ultrasound, and optical methods, each modality offers a characteristic response to structural or metabolic parameters of tissues and organs of human body.

Medical imaging is a process of collecting information about a specific physiological structure (an organ or tissue) using a predefined characteristic property that is displayed in the form of an image. For example, in X-ray radiography, mammography and computed tomography (CT), tissue density is the characteristic property that is displayed in images to show anatomical structures. The information about tissue density of anatomical structures is obtained by measuring attenuation to X-ray energy when it is transmitted through the body. On the other hand, a nuclear medicine positron emission tomography (PET)[6, 7] image may show glucose metabolism information in the tissue or organ. A PET image is obtained by measuring gamma-ray emission from the body when a radioactive pharmaceutical material, such as flurodeoxyglucose (FDG)[6] is injected in the body.

A. X-Ray Imaging

X-rays[1, 6] were invented by in Conrad Rontgen in 1895 who described it as new kind of rays which can penetrate almost anything. He described the diagnostic capabilities of X-rays for imaging human body and received the Nobel prize in 1901. X-ray radiography is the simplest form of medical imaging with the transmission of X-rays through the body which is then collected on a film or an array of detectors. The attenuation or absorption of X-rays is described by the photoelectric and Compton effects providing more attenuation through bones than soft tissues or air The diagnostic range of X-rays is used between 0.5A and 0.01A.

Fig. 1: An X-ray mammography image with microcalcification areas.

X-ray conventional radiography creates a 2D image of a 3D object projected on the detector plane. Figure 1 shows a 2Dmammography image of a female breast. Several micro-calcification areas can be seen in this image. While 2D projection radiography may be adequate for many diagnostic applications, it does not provide 3D qualitative and quantitative information about the anatomical structures and associated pathology that is necessary for diagnostics and treating a number of diseases or abnormalities.

B. X-Ray Projection Angiography

Angiography[6] is a diagnostic and, increasingly, therapeutic modality concerned with diseases of the circulatory system. Many imaging modalities (ultrasound, computed tomography, magnetic resonance imaging, angioscopy) are now available, either clinically or for research, to study vascular structures. In this method, the vessel of interest is opacified by injection of a radiopaque contrast agent. Serial radiographs of the contrast material flowing through the vessel are then acquired. This examination is performed in an angiographic suite, a special procedures laboratory, or a cardiac catheterization laboratory.

Digital imaging technology has become instrumental in the acquisition and storage of angiographic images. The most important application of digital imaging is digital subtraction angiography (DSA). Temporal subtraction is a DSA model in which a preinjection image (the mask) is acquired, the injection of contrast agent is then performed, and the sequential images of the opacified vessel(s) are acquired and subtracted from the mask. The result, ideally, is that the fixed anatomy is canceled, allowing contrast enhancement (similar to computed tomographic windowing and leveling) to provide increased contrast sensitivity.

C. Mammography

Mammography [5, 6] is an x-ray imaging procedure for examination of the breast. It is used primarily for the detection and diagnosis of breast cancer, but also for pre-surgical localization of suspicious areas and in the guidance of needle biopsies.

Breast cancer is a major killer of women. However, it has been demonstrated that survival is greatly improved if disease is detected at an *early stage*. Mammography is at present the most effective means of detecting early stage breast cancer. It is used both for investigating symptomatic patients (diagnostic mammography) and for screening of asymptomatic women in selected age groups.

Breast cancer is detected on the basis of four types of signs on the mammogram:

1. The characteristic morphology of a tumor mass.
2. Certain presentations of mineral deposits as specks called microcalcifications[6].
3. Architectural distortion of normal tissue patterns caused by the disease.
4. Asymmetry between corresponding regions of images of the left and right breast.

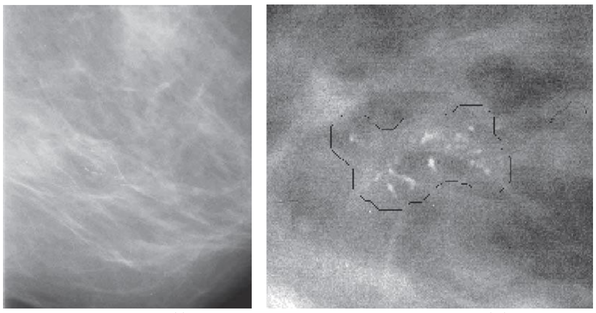
III. MULTIMODAL IMAGING APPLICATION

Digital image processing is cross disciplinary in nature. It uses ideas and techniques from optics, solid-state physics, electronics, computer architecture, software design, algebra, statistics, graph theory and more, and applies them to images from every field of the natural sciences and the technical disciplines. Knowledge of the application area, not only knowledge of image processing techniques, is required to obtain the best solution to a particular problem.

The applications are many and constantly increasing. Following shows numerous examples but is not exhaustive. They illustrate that image processing enables complex phenomena to be investigated, which could not be adequately accessed using conventional measurements. Although the techniques for processing and analyzing images are universal, we will be applying them mainly to medical images obtained from medical imaging systems or modalities. This application provides ways to look inside the human body and diagnose disease non-invasively without having to cut the body open through surgery, or put something into it such as an optical fiber or endoscope.

A. Computer-Aided Diagnosis in Mammography

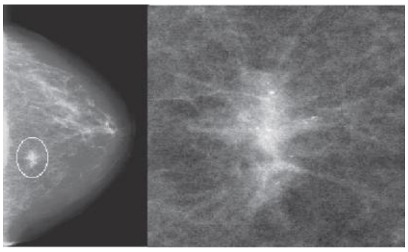
Mammography is the single most important technique in the investigation of breast cancer[6], the most common malignancy in women. It can detect disease at an early stage when therapy or surgery is most effective. However the interpretation of screening mammograms is a repetitive task involving subtle signs, and suffers from a high rate of false negatives (10–30% of women with breast cancer are falsely told that they are free of the disease on the basis of their mammograms[6].Computer-aided diagnosis (CAD) aims to increase the predictive value of the technique by pre-reading mammograms to indicate the locations of suspicious abnormalities, and analyze their characteristics, as an aid to the radiologist. About 90% of breast cancers arise in the cells lining the milk ducts of the breast, and are known as ductal carcinoma in situ (DCIS)[6]. Once the tumor extends beyond the lining of the ducts it is termed invasive, and can spread (metastasize) to other sites in the body. Radiographic indications fall mainly into two categories, microcalcifications and lesions. Microcalcifications[6] are the primary means of detecting in situ carcinomas; they are typically on the order of several hundred microns or smaller in diameter, comprise calcified dead cells, and tend to occur in clusters (Fig. 2).



(i) (ii)

Figure 2: (i) A mammogram showing a cluster of microcalcifications and (ii) computer-estimated margin around a cluster of microcalcifications.

Most lesions are invasive cancers; they are ill-defined in shape, often with tissue strands or spiculations radiating out from them, and similar in radio-opacity to the surrounding normal tissue (Fig. 3).



(i) (ii)

Figure 3 (i) A mammogram showing a stellate lesion and (ii) a magnified image of the lesion.

The imaging requirements in mammography are stringent, both in terms of spatial and contrast resolution. Computer-assisted diagnosis of mammograms involves image processing, segmentation and feature extraction. Segmentation of the breast region serves to limit the search area for lesions and microcalcifications. Background subtraction may be necessary to compensate for a varying background optical density in the anode–cathode direction of the mammography system, known as the heel effect: simple subtraction of the low-pass filtered image from the original image can be effective .

Noise in the image can be reduced by median filtering [23], although this can disturb the shape and/or contrast of small structures. An improved technique combines the result of morphological erosion and dilation using multiple structuring elements.

Microcalcifications can be described by the morphology (shape, area, brightness, etc.) of individual calcifications and the spatial distribution and heterogeneity of individual calcifications within a cluster. They can be enhanced by spatially filtering the mammogram twice, once to enhance the signal-to-noise ratio and a second time to suppress it, and taking the difference of both images. An alternative is to threshold the image, and morphologically open it using a structuring element to eliminate very small objects while preserving the size and shape of the calcifications.

D. Tumor Imaging And Treatment

Multi-modality imaging is essential in the diagnosis and treatment of cancer (Fig. 4).

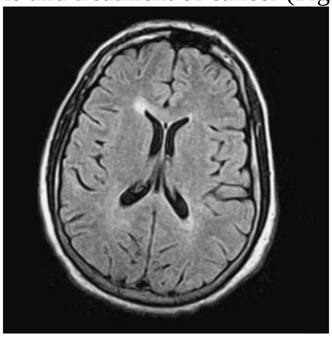


Figure 4: T1-weighted spin echo image of the head.

In diagnosis it is used to detect, localize and characterize the “tumor burden”. Once a tumor is characterized, imaging is used in guiding surgical resection and radiation treatment planning (RTP) and assessment of treatment. Each imaging modality – radiography, CT, SPECT, MRI, PET and others – provides complementary information to understand better the structure and function of the tumor and adjacent organs[6]. Progress in imaging systems has enabled the acquisition of volumetric data sets from which the tumor can be visualized with appropriate rendering .

Dynamic imaging uses a tracer material injected into the circulatory system, the kinetics of the tracer distribution providing functional information. The tracer or contrast material is administered as a bolus that propagates through the circulatory system and is detectable by the imaging modality. Different tracer materials have been developed for specific imaging modalities. The functional nuclear medicine modalities rely on the uptake and/or metabolism of a radioactive tracer to identify and characterize high-grade recurrent tumors: the poor spatial resolution of these modalities precludes their use for detecting small (<0.5 cm diameter) tumors. It is important to be able to distinguish benign from malignant tumors, and this can be achieved by studying the microcirculation and/or oxygenation status. High tumor perfusion is indicative of a high blood and oxygen supply to the tumor, which are key elements in its growth. Perfusion imaging is done using contrast-enhanced computed tomography or magnetic resonance imaging, as well as with nuclear medicine methods and ultrasonography.

Combination CT/PET scanners are now available commercially: the PET scan picks up the metabolic signal of actively growing cancer cells in the body, and the CT scan provides a detailed picture of the internal anatomy that reveals the size and shape of abnormal cancerous growths. When the two images are fused together they provide accurate information on both tumor location and metabolism. The goal of three-dimensional radiation therapy planning is to deliver a lethal dose to cancer cells without damaging surrounding healthy tissue, some of which (e.g. the brain stem and optic nerve) may be extremely sensitive to ionizing radiation, in order to minimize side effects. Figure 5 shows a fused CT/PET image of a slice through the head of a patient with a tumor in the nasal cavity in front of the brain. The lines represent incremental levels of radiation dose, encircling the tumor, computed by a three-dimensional conformal treatment plan. The brain, eyes and lenses receive only minimal doses of radiation, about 10% of the tumor dose.

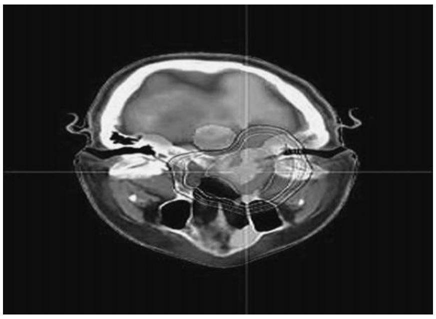


Figure 5: Fused CT/PET image showing radiation iso-dose lines around a nasal tumor.

E. Angiography

Coronary artery disease is the leading cause of death worldwide. It occurs when the coronary arteries[6] that supply blood to the heart muscle become hardened and narrowed due to the build-up of plaque (fat deposits) on their inner walls, termed atherosclerosis. As the plaque increases in size, the interior of the arteries, the lumen, gets narrower (stenoses) and less blood can flow through them. Eventually, blood flow is reduced and the heart muscle does not receive sufficient oxygen. This can result in a myocardial infarction (heart attack) when a blood clot develops at the site of the plaque and suddenly cuts off most or all of the blood supply causing permanent damage to the heart muscle.

Once the lumen becomes impaired it can be studied by x-ray arteriography using a radio-opaque contrast agent injected into each artery with a small tube-like device, a catheter, under fluoroscopic guidance. X-ray arteriography is a two-dimensional projection technique, with biplane (preferably orthogonal) measurements often taken to characterize the stenosis under the assumption of an elliptic cross-section .

Enhancement of vessel edges for better visualization can be easily realized in real time using unsharp masking , but it increases the errors in the measured diameters in quantitative coronary arteriography and is not recommended. The reconstruction of three-dimensional space from two-dimensional projections is ambiguous. However, on-line three-dimensional reconstruction of the coronary arterial tree, based on two views acquired from routine angiograms at arbitrary orientation and using gantry angulations, has been used to give multiple projection images, from which a set of views with minimal vessel overlap are chosen. Intravascular ultrasound imaging (IVUS)[6], a catheter-based technique which provides real-time high-resolution tomographic images of both the lumen and the arterial wall, is complementary to x-ray angiography. An array of miniaturized solid-state transducers in a cylindrical pattern acquires cross-sectional images. The catheter is navigated using the three-dimensional path from the biplane images, and the local coronary artery cross-section reconstructed from the IVUS data. Segmentation of these images to show lumen and plaque is made easier by using multi-frequency transducers. The lumen can then be reconstructed and rendered in three dimensions, with each cross-section registered to it for visualizing the extent of the plaque and precise measurement of the stenosis (Fig.6).

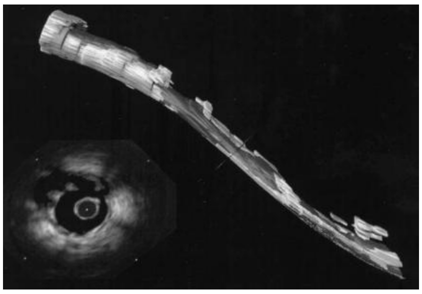


Figure 6 Three-dimensional visualization of coronary artery reconstructed from sequence of intravascular ultrasound images

Such an image-guided system can be used to diagnose the disease, deliver radiation of topical chemicals to the plaque, or position a rigid support tube, a stent. Magnetic resonance angiography (MRA) has a similar spatial resolution to computed tomography angiography. It also potentially allows the assessment of myocardial function, perfusion and metabolism in the same acquisition session, making it a very attractive and powerful technique. However it offers a bewildering array of data acquisition protocols, each providing somewhat different angiographic information: its greatest challenge is in selecting the optimal protocol for producing the most diagnostic images in the shortest scan time.

IV. CONCLUSION

Multi modal medical imaging is an advanced medical imaging which are frequently and widely used by the doctors in the field of medical diagnosis.. With the emergence of medical imaging techniques, researchers and practitioners started by applying this technology on medical diagnosis in various fields such tumor detection, bone fractures, and advance medical imaging The usage of medial imaging in the medical industries opens new possibilities in decision making to the top management, and to advisory and control systems. The applications of medical imaging in any hospital and pharmaceutical industries have opened up new possibilities in decision-making and predict the accurate diagnosis of the patient. This technology is helping biochemists, biologists, medical scientists, and physicians to obtain quantitative measurements, which facilitate the validation of scientific hypothesis and accurate medical diagnosis. Images of human organs such as the heart, breast, lung, and brain, play an important role in diagnostic radiology, psychiatry, cardiology, and internal medicine.

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