Breast Cancer Detection and Screening Techniques: A Survey

Harmandeep Singh* and Damanpreet Singh**
*Research Scholar,Department of Computer Science & Engineering, Punjab Technical University, Jalandhar, (India)
singh.harman.saini@gmail.com
**Associate Professor, Department of Computer Science & Engineering, SLIET Longowal, Sangrur, (India)
damanpreetsingh@sliet.ac.in

Abstract: Breast cancer is one of the most prevalenttype of cancer in human body. The best and viable treatment of breast cancer is its early detection. In modern medical science there exist plenty of techniques and methodologies for timely detection of breast cancer. In this paper a thorough and exhaustive analysis of existing breast cancer detection techniques has been carried out by discussing different aspects like reliability, affordability and outcomes.

Keywords: Mammograms, Computer Aided Diagnosis\Detection, Micro-calcification, Sensitivity and Specificity.

Introduction

In today's modern era the most common malignancy in women across the world is breast cancer. Breast cancer is also found in men but the ratio of cases encountered is low. The breast cancer in women can spread in two ways firstly, in the tissue of breast, usually in the ducts and second is in lobules[1]. The only strategy for breast cancer control is early detection. Modern medical science has devised plenty of techniques and methodologies for early detection of breast cancer. Mammography is currently the best imaging modality for early detection of breast carcinoma. The findings of mammography are based on anatomic changes in the breast and it is the best method of choice in screening asymptomatic women[2]. Nevertheless, while mammography has relatively high sensitivity for the diagnosis of breast cancer, its specificity and positive predictive values are low. The main limitation of mammography is that it cannot always differentiate benign lesions from malignant especially in the case of women with dense breasts or those who have architectural distortions of their breasts following radiation therapy or surgery or those with breast implants. Therefore abnormalities detected during mammography frequently results in biopsy and the resulting outcome is that many women without cancers are biopsied. Fewer than 5% of breast cancers are attributable to mutations of breast cancer genes namely BRCA1 and BRCA2 [3].

The limitation associated with the use of mammography has led to the development of complementary and new modalities including Ultrasound Imaging, Magnetic Resonance Imaging(MRI), Scientimammography, Thermography, Tomosynthesis and Computer Aided Detection\Diagnosis(CAD). In this research study an attempt has been made to provide an insight of the available various breast cancer detection techniques and their numerous impacting factors such as performance, accuracy and affordability.

The paper is organized as follows: Section 2 discusses the various breast cancer detection techniques namely mammography, breast thermography, magnetic resonance imaging (MRI), breast ultrasound, tomosynthesis, scintimammography, electrical impedance tomography, positron emission tomography (PET), near infrared optical imaging and computer-aided detection/diagnosis (CAD) and pros and cons of each technique. Section 3 concludes the review with an elaborative discussion.

Breast Cancer Detection Techniques

Mammography: Mammography is the most widely used method of detecting early breast cancer which is not clinically tangible. It is used to locate small foci of cancer within the breast which otherwise cannot be diagnosed[5]. This has resulted in a 30% reduction in the mortality of breast cancer in women[6]. Every woman should have her first screening mammography at the age of 40, annually or every other year between the ages of 40 and 49, and annually after the age of 50. Breast physical examination by a well-trained physician is also recommended at the same intervals. It is recommended that breast self-examination starts at age 20 and be performed on a monthly basis[4]. Mammography is quite sensitive in detecting breast cancer, but it cannot be used to accurately differentiate benign from malignant lesions. The only means of confirmation of a suspicious lesion seen on mammography is excisional biopsy. In recent years, the clinical use of fine-needle aspiration cytology and stereotactic core biopsy of the breast has become more common. Although these techniques are very simple but these techniques require a trained cytopathologist and costly equipment[2][4].While screening mammography is recognizedas the most effective method for early detection of breast cancer,this modality has the following limitations[7]:

- Up to 20% false-negative rates, where mammography fails to detect cancers.
- Up to 12% false-positive rates, where mammography detects a cancer when there is none.
- Inadequate detection of cancer in women with dense breast tissue. Mammography detects approximately 90% of tumors in women over 50, but only 60% of tumors in women under the age of 50.
- Lack of specificity, where mammography cannot distinguish between benign and cancerous breast lesions.

Breast Thermography

Basic Principle: “All objects above zero Kelvin emits infrared radiation. The Stefan-Boltzmann law gives the relationship between the infrared energy and temperature. Emissivity of human skin is high (within1 percent of that of blackbody) therefore measurements of infrared radiation emitted by skin can be directly converted to temperature. This process is known as Infrared Thermography”[8].

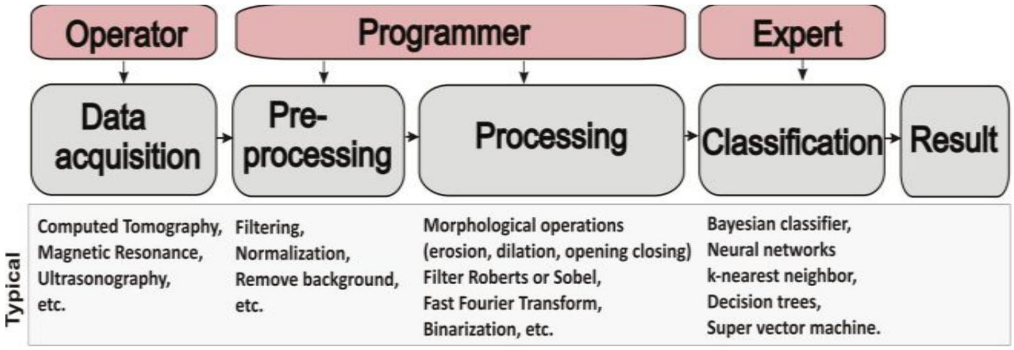

Figure1. Block diagram for analysis of thermographic images[12]

Technique: Breast Thermography is a diagnostic process that takes images of the breasts for early detection of breast cancer. It is an important tool in Breast cancer Screening[9][10]. The procedure uses the principle that chemical and blood vessel activity in both precancerous tissue and the area surrounding the tissue in breast cancer is almost always higher than in the normal breast[11]. However precancerous and cancerous masses are highly metabolic tissues and they need a large amount supply of nutrients to maintain their growth. So to do this they increase circulation of their cells by sending out chemicals to keep existing blood vessels open and create new ones (neoangiogenesis). This process results in an increase in surface temperatures of the breast. Breast Thermography uses an infrared camera and computer to detect analyse and produce high resolution images of these temperature changes in the breast[12][13].

Magnetic Resonance Imaging: MRI has been used for a wide variety of medical applications. Early efforts with breast MRI were disappointing; however, the use of intravenous agents with a dedicated breast MR coil represented a clear advance in the technology[14]. MR images are created by recording the signals generated after radio frequency excitation of nuclear particles in tissue exposed to a strong magnetic field. The signals have characteristics that vary according to tissue type. Most breast MRI uses a contrast agent, gadolinium-DPTA. The basic idea behind this is similar to that discussed with iodinated contrast mammography. The contrast agent, injected into the patient’s bloodstream, accumulates in the vascular system, and can locate tumors by highlighting areas containing a dense blood vessel network. Like contrast mammography, usually several scans are taken: one prior to contrast agent injection and one or more after the injection. The pre-contrast and postcontrast images are compared and areas of high uptake of the contrast agent are analyzed. Today, MRI is a generally accepted diagnostic procedure for a number of breast related indications. Its greatest advantage is that it is very sensitive to tumors[15]. If a suspected area does not exhibit contrast agent uptake, the probability that it is malignant is very small. On the other hand its specificity is poorer. If the area does show enhancement, it may or may not be a tumor. Further imaging or biopsy may be needed to resolve the question. MRI is also used to image breast tissue near implants, where x-ray mammography is poor. In addition, it is useful, following breast cancer diagnosis, as a guide for tumor staging, as well as for post interventional therapy monitoring and detecting local recurrence. Perhaps its biggest limitations are its costs and the lack of general geographic availability. MRI is also more time-consuming than mammography, both in the acquisition and the readings, and it requires contrast agents. There is an FDA-approved system designed specifically for breast MRI. Ongoing clinical studies are currently evaluating the usefulness of MRI screening for high-risk patients or women with mammographically unsuitably dense breasts[4].

Breast Ultrasound: Each year, mammography is used to screen more than 44 million women in the U.S. Of those women, 36% (approximately 16 million) are referred for a second, diagnostic test[16]. Many of these women are given a breast ultrasound exam. Ultrasound waves are high-frequency sound waves thatreflect at boundaries between tissues with different acousticproperties. The depth of these boundaries is proportional to thetime intervals of arrivals of reflections. Thus, ultrasound can map animage of boundaries of tissues. Ultrasound can also provide informationabout blood flow by mapping the amount of acoustic frequencyshift as a function of position in tissue; this is the Doppler Effect.Ultrasound holds promise as a method for detection ofcancers in women with dense breast tissue, which is oftenproblematic with conventional screen-film mammography[17].Ultrasound has also assumed an important role in breast imaging,as a supporting technique to diagnostic mammography for palpable mass evaluation,biopsy guidance, and evaluation of benign masses.In the last few years, great significant progress has been made in improvingimage quality and resolution of all ultrasound machines. Theseimprovements were the result of new transducer design technologyand advances in electronic signal processing.A limitation of conventional ultrasound is its poorability to detect small calcifications in the breast, or microcalcifications.These microcalcifications range from 50 to severalhundred microns in diameter, and they may be an importantearly indication of breast cancer. Small calcifications with ultrasoundare difficult to interpret due to a phenomenon, called“speckle,” that arises from the interaction of the ultrasound fieldwith tissue. Speckle may produce small brightechoes within tissue that have an appearance quite similar to smallcalcification, making detection of true calcifications difficult.Conventional ultrasound generates images using a beamthat strikes tissues from a single direction. In modern science a number of techniques have been developed to improve ultrasound images and using these techniqueshave made it possible to generate an ultrasound image using severalbeams that strike the tissue from several angles. This technique,called compound imaging, allows for the suppression of artifactsand the reinforcement of real structures. The result is improvedcontrast and detail resolution with improved visualization ofborders and interfaces. However, the use of compounding mayreduce the display of clinical markers such as shadowing andposterior enhancement.The detection of tumor blood supply may prove to beimportant in the differentiation of benign and malignant masses.Doppler ultrasound permits the identification of blood flowwithin some breast masses, but has limited sensitivity.3D ultrasound images permits the examination of avolume of tissue, rather than a single slice. Researchers havedeveloped innovative techniques for registration of images from 3Ddata sets, allowing more accurate measurement of tumor volumeand comparison of changes in the mass size over time.A novel use of ultrasound in the breast currently underdevelopment is elastography[18]. This technique uses information from theultrasound signal to produce an image displaying the elasticproperties of breast tissue. Elastography is able todetect and display differences in tissue stiffness like palpation. As most cancersare hard in comparison to the tissues that surround them,elastography provides a high contrast image, in some casesrevealing features that may not be visible with conventionalultrasound or mammography.Although mammography will most likely continue to be theprimary means of identifying small calcifications that correlatewith certain types of cancer, ultrasound is becoming increasinglyuseful as an adjunct modality to mammography[19].

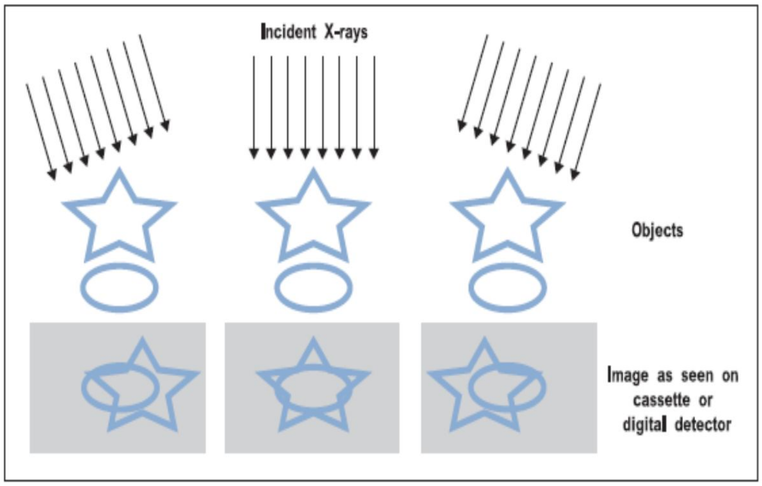

Figure 2. Tomosynthesis Imaging acquires the images from different angles[4].

Tomosynthesis: Wolfe has reported the relationship between breast tissue density and breast cancer risk as early as 1976.Since then, the breast density is considered as a significant risk factor and has been debated very much. It has been reported that there is a 2 to 6 fold increase in the risk of breast cancer in women with dense breast compared with those with a fatty breast. This increased risk is significant because 50% of women between 40 and 49 years old and 30% of women from 70 to 79 years old have approximately 50% dense breasts. Studies have shown the great risk for breast carcinoma increases with increase in breast density. In 1995, Byrne et al. reported an almost fivefold increase in risk of breast cancer in women who had a breast density of 75% or greater as compared with women who had fatty breasts tissues. Fewer than 5% of breast cancers are attributable to mutations of the breast cancer gene (BRCA1 and BRCA2). Furthermore, it has been suggested that mammography screening effectiveness is reduced in patients with high-risk parenchymal patterns [3].

A well-known limitation of conventional 2D mammography is tissue superimposition, which can contribute to lesions being obscured. Breast tissue superimposition can occur to a greater degree in dense breast tissue; it has been reported that only half of cancers will be visible in extremely dense breast tissue[20][21]. As technology has advanced, the sensitivity of mammography has improved. In the Digital Mammographic Imaging Screening Trial, Pisano et al. reported the accuracy of full-field digital mammography (FFDM) to be significantly higher than that of film-screen mammography in women with heterogeneously dense and extremely dense breasts[22][3]. DBT is the latest breast imaging tool that is gaining widespread adoption because it can to improve the limitations of 2D mammography, particularly improving on the detection of lesions in dense breast tissue. The DBT device is an FFDM system capable of producing standard 2D images and tomosynthesis images. The 2D and DBT image datasets can be acquired independently or in combination under the same compression. In tomosynthesis, the x-ray tube moves in a limited arc across the breast and a series of low-dose images are acquired from different angles. The images are then reconstructed into 1-mm slices. The ability to view the breast in slices can provide improved lesion visibility within the cross section of the breast tissue[2]. Early in the clinical implementation of tomosynthesis, the results of studies promised that tomosynthesis would help to improve the accuracy of diagnostic and screening mammography, reduce recall rates, and provide accurate 3D lesion localization. The tomosynthesis imaging method is hoped to help to improve the detection and characterization of breast lesions especially in women with non-fatty breasts[19][23].

Scintimammography: Scintimammographyis a nuclear imaging technique that uses radio nuclides to image malignant breast tumors; it requires the administration of a γ-ray-emitting radio tracer to the patient and a γ- camera forimaging.The ideal radiopharmaceuticals for scintimammography would show high and specific tumor up take and minimal activity within the normal breast tissue[24].The most widely used models are Tc-99m sestamibiand Tc-99m tetrofosmin, two small cationic complexes oftech-netium that were introduced for myocardial perfusionimagingand were then proposed as tumor-seeking agents[4]. Tc-99m sestamibiuptake and retention in cancer cells depends onmanyfactors such as regional blood flow, angiogenesis and tissue metabolism, plasma and mitocondrial membrane potential with approximately 90% of tracer activity concentrated in the mitochondria. Similar mechanisms have also been suggested for Tc-99m tetrofosmin, however, Arbaband colleagues demonstrated, in tumor cell lines, that tetrofosmin uptake depends on both mitochondriapotentials aand cell membrane with only a small fraction accumulating inside themitochondria. Following the injection,the prone positions are imaged, which provides improved separation of the breast tissue from the myocardium and the liver, which always show a high up take and may mask overlying breast activity. The position that are proneal so allows evaluation of deep breast tissue from the myocardium, the liver and the thoracic wall, and provides natural landmarks of breast contours, which are very important for lesion localization.Two lateral views in the prone position are usually performed with a special cushion that enables the examined breast to hang freely through an opening, very close to the collimator of the γ-camera. In addition, an anterior chest image with the patient in the supine position is required for better localization of primary tumors in the inner quadrants and also to visualize the axillary and possibly internal mammary lymph-node involvement[2].

Electrical Impedance Tomography: Different tissues in our body have different characteristic conductivities and permittivities. Thus they offer different resistance to an electric current when passed through it. This property is used in the method of electrical impedance tomography[25]. Typically a malignant tissue shows a variation in the output voltage thereby indicating its presence. This is because a malignant tissue shows much higher conductivity and permittivity than a normal tissue. A number of electrodes are connected to the breast tissue. A current of different frequencies is applied at various times. The results give a general idea of the trends of impedances. Magnitude and phase is calculated at each electrode. Deviation at each electrode for a malignant tissue is calculated. A current is injected using two electrodes which produces a current distribution. The field image is reconstructed using tools like FEMM and EIDORS. Clay and copper used to simulate benign and malignant cells due to their unique conducting properties EIT has an advantage of being inexpensive and no safety hazards unlike the MRI and other methods. It can very well detect tumors which are small in size. EIT offers a very low resolution reconstruction of the tissue.This can however be overcome by increasing the number of electrodes[4]

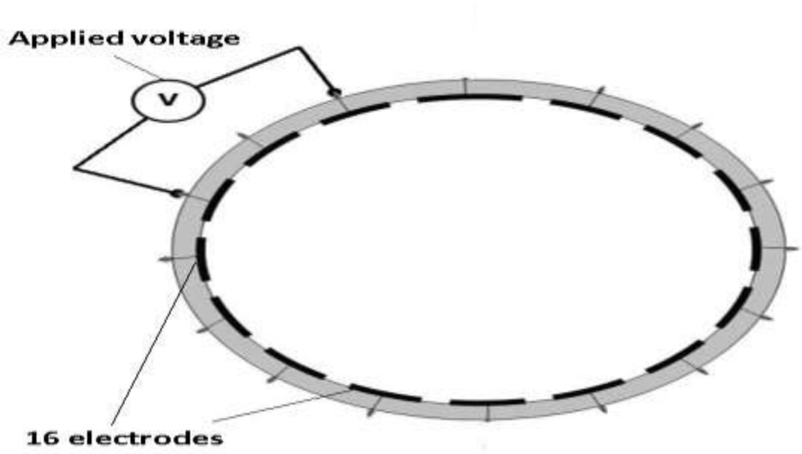

Figure3. Set-up for Electrical Impedance Tomography[26].

Positron Emission Tomography (Pet): PET is used in the U.S. for restaging and evaluating recurrent breast cancer. A number of commercial systems are available for use in breast cancer applications[4]. In PET, a small amount of radioactive glucose, usually 18-fluoro-2-deoxyglucose (FDG), is injected into a vein, and a nuclear camera generates images that highlight areas of high tracer uptake. Like contrast mammography and contrast MRI, glucose accumulates in tissues of high growth. In particular, glucose goes to areas of high glucose utilization or metabolism. Aggressive tumors are a type of tissue in the body where metabolism is rapid[26]. The result of the PET scan is a set of images showing the distribution of the drug in the breast. A number of breast specific PET scanners are currently in development and in early clinical trials to demonstrate efficacy[27].

Near Infrared Optical Imaging: A number of near infrared optical imaging technologies are currently under development in the U.S., but there are no FDAapproved products at this time. This technology uses light emitting diodes to transmit near infrared light through the breast to produce an image[4]. The systems measure the absorption of light at several different frequencies, and can differentiate oxygenated from de-oxygenated hemoglobin. Image-processing algorithms are then used to highlight areas of vascular development (angiogenesis) and/or hypermetabolism (hemoglobin and oxygen saturation levels). Images have very poor resolution; however, optical scanning is able to penetrate deeply into the breast, uses no radiation, and so is completely non-invasive. A major advantage is patient comfort, because the breast is not compressed[26].

Computer-Aided Detection/Diagnosis (Cad): Mammography is considered as the most effective tool for earlydetection of breast cancer but it has some limitations as false-positive values and false-negative values. Due to this the radiologists fail to detect 10% to 30% of breastcancers. The false-positive value means thepercentage of lesions that were found to be cancerous andsubjected to biopsy. The miss rate in mammography isincreased in dense breasts where the probability of cancer is4 to 6 times higher than in non-dense breasts. Recently, computer-aided detection/diagnosis(CAD) systems have been designed to reduce the expenseand to improve the radiologist’s capability in interpretationof images and differentiation between benign andmalignant tissues. The outputs are derivedusing various techniques in computer vision to present someof the important parameters such as the location ofsuspicious lesions and the likelihood of malignancy ofdetected lesions[18].
CAD systems are classified into two categories:computer-aided detection (CADe) systems and computer-aideddiagnosis (CADx) systems. The CADe systems aredesigned to help the radiologist in detecting and locatingthe suspicious area in breast images, while the CADx systems aredesigned to classify benign or malignanttissues. This article reviews some of the most recent advances inbreast cancer detection/diagnosis using CAD systemsdeveloped for mammography and ultrasound.

CADe: The CADe systems are developed help radiologists todetect and locate abnormalities in breast screening images.In CADe systems firstly the suspiciousregions are detected. The important algorithms to identify theregions of interest (ROIs) are region-based or pixel-basedmethods. The pixel-based methods are easy to implement but theirdrawback is their computationally intensive process. Inregion-based detection techniques, ROIs are extracted by usingsegmentation techniques. Since region-based methodsconsider morphology and size of masses, they are less complex than pixel-based methods[18].

CADx: In order to reducethe number of biopsy recommendations on benign lesionsCADx systems are used to characterize suspicious lesions.Computer vision and artificial intelligent techniques are mainly usedto characterize an ROI as benign or malignant. In order to create aCADx system, the integration of various image processingoperations, such as image segmentation, feature extraction,feature selection, and classification, is essential.Segmentation is essential for CADx system[18].Segmentation is the most rigorous stage in the computeraideddiagnosis of calcification due to small size ofmicro-calcification. The two major categories of segmentationmethods are region-growing and discrete contour models.

Conclusion

This research study overviewed the techniques and methodologies for the early detection of breast cancer so that proper treatment can be given to the cancer patient for improving his life quality. Mammography technique is widely used for early stage breast cancer detection but due to its limitations and negative effects on human body other techniques are also devised. To eliminate the shortcomings of mammography extensive research has been carried out in supporting and new technologies. The newer methodologies like ultrasound imaging, MRI, PET scans, thermography, tomosynthesis and CAD are supportive in the sense that they help in charting the modalities of treatment. Current research in this field seems to be advancing towards technologies which can offer more precise and early diagnosis.

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