Multimodality Breast Imaging
Diagnosis and Treatment

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SPIE PRESS
Bellingham, Washington USA

Library of Congress Cataloging-in-Publication Data

Multimodality breast imaging : diagnosis and treatment / editors, E.Y.K. Ng, U. Rajendra Acharya, Rangaraj M. Rangayyan, and Jasjit S. Suri.
pages cm
Includes bibliographical references.
ISBN 978-0-8194-9294-4
1. Breast–Imaging. I. Ng, Y. K. Eddie, editor of collaboration. II. Acharya U, Rajendra, editor of collaboration. III. Rangayyan, Rangaraj M., editor of collaboration. IV. Suri, Jasjit S., editor of collaboration.
RG493.5.D52M85 2013
618.1′90754–dc23
2012042251

Published by
SPIE
P.O. Box 10
Bellingham, Washington 98227-0010 USA
Phone: +1 360.676.3290
Fax: +1 360.647.1445
Email: Books@spie.org
Web: http://spie.org

Cover background image courtesy of SuperSonic Imagine.

Printed in the United States of America.
First printing

SPIE

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Preface

Breast cancer is an abnormal growth of cells in the breast, usually in the inner lining of the milk ducts or lobules. It is currently the most common type of cancer in women in developed and developing countries. The number of women affected by breast cancer is gradually increasing and remains as a significant health concern. Hence, the early detection of breast cancer can improve the survival rate and quality of life. Therefore, today, newer modalities are available to more accurately detect breast cancer. Researchers are continuously working to develop novel techniques to detect early stages of breast cancer. This book covers breast cancer detection using different imaging modalities such as mammography, magnetic resonance imaging, computed tomography, positron emission tomography, ultrasonography, infrared imaging, and other modalities.

Architectural distortion is one of the major causes of false-negative findings in the detection of early stages of breast cancer. Chapter 1 presents methods for computer-aided detection of architectural distortion in mammograms acquired prior to the diagnosis of breast cancer in the interval between scheduled screening sessions. The results are promising and indicate that the proposed methods can detect architectural distortion in prior mammograms taken 15 months (on average) before clinical diagnosis of breast cancer, with a sensitivity of 0.8 at 5.2 false positives per patient.

A computer-aided system for the automated detection of normal, benign, and cancerous breasts using texture features extracted from digitized mammograms and data mining techniques is proposed in Chapter 2. The novelty of this work is to automatically classify the mammogram into normal, benign, and malignant classes using the texture features alone, with an efficiency of 93.3% and sensitivity of 92.3% using a fuzzy classifier.

Breast cancer diagnosis by combination of fuzzy systems and an ant colony optimization algorithm is proposed in Chapter 3. Results on the breast cancer diagnosis dataset from the University of California Irvine machine learning repository show that the proposed FUZZY-ACO would be capable of classifying cancer instances with a high accuracy rate and adequate interpretability of extracted rules.

Chapter 4 discusses a computer-aided diagnosis system tested on magnetic resonance datasets obtained from different scanners, with a variable temporal and spatial resolution and on both fat-sat and non–fat-sat images, and has shown promising results. This type of system could potentially be used for early diagnosis and staging of breast cancer to reduce reading time and to improve detection, especially of the smaller satellite nodules.

Imaging plays a pivotal role in the evaluation of metastatic spread of breast cancer disease. Chapter 5 gives an overview of the recent developments in breast cancer imaging, in terms of instrumentation and clinical applications. In addition, the theoretical framework behind advanced imaging modalities is highlighted to provide background knowledge to the reader, and potential future research directions are also presented.

The role of positron emission tomography is established in the practice of oncology. The advances in functional and molecular imaging techniques have increased the accuracy in the diagnostic evaluation of breast cancers and is discussed in detail in Chapter 6.

Chapter 7 discusses 3D whole-breast ultrasonography, which can provide the entire breast anatomy for later review. The 3D whole-breast ultrasound procedure and the training time are simpler and shorter than the traditional 2D US. It also provides interoperator consistency, and its reproducibility is better for follow-up studies.

Recent progress in medical ultrasound has paved the way for the evaluation of breast cancer. State-of-the-art high-resolution ultrasound can detect tiny breast lesions as small as 1–2 mm in size, and sometimes microcalcifications even less than 0.5 mm, or small carcinomas 3–6 mm in diameter. Chapter 8 presents an overview of the recent developments in ultrasound imaging of breast cancer, in terms of instrumentation and clinical applications.

Nonlinear features such as Lyapunov exponents are used to differentiate malignant and benign breast thermograms in Chapter 9. This work can be extended for classifying different stages of breast cancer. The authors are currently working toward these objectives.

A set of image features describing bilateral differences between left and right breast regions in thermograms is described in Chapter 10. These features are then used in a pattern classification stage to discriminate malignant cases from benign ones. Classification is performed by fuzzy if-then rules and applies a genetic algorithm to optimize the rule base, and secondly uses an ant colony optimization classification algorithm. Both approaches have shown good classification accuracy.

Infrared imaging has shown to be a promising technique for the early diagnosis of breast pathologies and as a screening technique. The concept of a combined diagnostic enables a high degree of specificity and sensibility in such diagnosis. Chapter 11 presents a concept of merging information from the images with other modalities of examination, such as mammograms and ultrasound, in order to improve the early detection of breast pathologies, including cancer.

Chapter 12 discusses diffuse optical imaging, which makes use of diffuse light to probe deep tissues by taking advantage of low tissue absorption within the near-infrared wavelength range (650–900 nm). The optical measurements obtained can be used to calculate optical properties, namely absorption and scattering within tissues. This, in turn, can provide information about physiological parameters within tissues, such as oxy- and deoxy-haemoglobin, and water and lipid, all of which can be utilized in the detection, characterization, and therapy monitoring of breast cancer.

Cytopathology is a branch of pathology that studies and diagnoses diseases on the cellular level, using samples of free cells or tissue fragments. Chapter 13 describes the results of a study of the features that are used by physicians and computers to diagnose cancer based on features in fine-needle aspiration cytology images. It discusses the significance of a cytological feature in representing its true ability to discriminate benign and malignant conditions of a breast lump in the Wisconsin Diagnostic Breast Cancer database.

Only a small number of studies have been reported on breast radiofrequency ablation, and most of them have included the posterior surgical excision of the treated breast. Chapter 14 presents the future trends in the development of more-specific radiofrequency algorithms for breast cancer treatment, to improve the results, determine the setting of the specific indications for the technique, and expand the study of long-term results and survival.

Breast conserving therapy is the gold-standard option for patients with early-stage breast cancer. The surgical excision removes the entire tumor with a negative surgical margin and helps to preserve the breast tissue as far as possible. Chapter 15 explains minimally invasive ablative techniques, which may offer complete tumor ablation, with less psychological morbidity, better cosmetic results, and shorter hospital stay.

A microwave-based imaging modality is an emerging noninvasive medical imaging approach exploring the dielectric property of biological tissue that shows great potential in breast cancer detection. Chapter 16 discusses a correlated microwave acoustic imaging modality and numerical simulation using finite-difference time-domain analysis. It is clearly shown that a combination of microwave-based imaging modalities is expected to provide an efficient diagnostic method for breast cancer detection in the future.

Fluorescence-based bioassays are novel diagnostic tools that are available to clinicians for deciding future treatment and to researchers for monitoring biological functions that may lead to novel investigations.

The different aspects of photonic crystal fiber, its guiding mechanism, the refractive index law, etc. are analyzed and explained in Chapter 17. The proposed methodology is implemented in an array format of immuno recognition of specific proteins using a hollow-core photonic crystal fiber.

An overview of a quality-assurance program for digital mammography is discussed in Chapter 18. This overview includes the quality-control test procedures based on the American College of Radiology and the International Atomic Energy Agency. The role of medical physicists in the mammography quality-assurance programs, including acceptance, annual, and regular quality-control testing, is briefly presented.

In this book, we have made an honest effort to present information and methodologies for accurate diagnosis of breast cancer to help researchers, doctors, teachers, and students in biomedical science and engineering.

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January 2013

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Acronyms and Abbreviations

ABSN	angles between surface normals
ABVS	Automated Breast Volume Scanner
ACO	ant colony optimization
ACR	American College of Radiology
ACS	ant colony system
AEC	automatic exposure control
AI	artificial intelligence
AJCC	American Joint Committee on Cancer
ALA	5-aminolevulinic acid
ANN	artificial neural network
ANOVA	analysis of variance
APC	antigen-presenting cell
APD	avalanche photodiode
ART	algebraic reconstruction technique
AUC	area under ROC curve
AUCEC	area under the contrast-enhancement curve
B + F	base + fog
BC	breast cancer
BCDSG	Breast Cancer Disease Site Group
BEM	boundary element method
BFGS	Broyden–Fletcher–Goldfarb–Shanno (method)
BHTE	bioheat transfer equation
BIRADS®	Breast Imaging Reporting and Data System
BIRADS-MRI	BIRADS for MRI
bpp	bits per pixel
BRCA-1, -2	breast cancer genes
BS	bone scintigraphy
BSE	breast self-examination
BWI	bound water index
CaCo	colorectal cancer
CAD	computer-aided diagnosis
CADe	computer-aided detection
CADx	computer-aided diagnosis
CAM	combined autocorrelation method

CBE	clinical breast examination
CCD	charge-coupled device
CDS	clinical decision support
CDSS	clinical decision support system
CDU	color Doppler ultrasound
CECT	contrast-enhanced computed tomography
CFD	computational fluid dynamics
CI	confidence interval
CLS	curvilinear structure
CMAI	correlated microwave acoustic imaging
CMM	coordinate measuring machine
CMOS	complementary metal-oxide semiconductor
CNS	central nervous system
CR	computed radiography
CR	contrast response
CT	computed tomography
CTL	cytotoxic T lymphocyte
CTS	chaotic time series
CW	continuous wave
CXR	chest radiology
DC	dendritic cells
DCE-MRI	dynamic contrast-enhanced MRI
DCIS	ductal carcinoma *in situ*
DCS	diffuse correlation spectroscopy
DD	density difference
DDSM	Digital Database for Screening Mammography
del	detector element
DeTr	decision tree
DICOM	Digital Imaging and Communications in Medicine
DM	digital mammography
DMD	digital micromirror device
DMIST	Digital Mammographic Imaging Screening Trial
DOI	diffuse optical imaging
DOS	diffuse optical spectroscopy
DOT	diffuse optical tomography
DR	digital radiology
DRS	diffuse reflectance spectroscopy
DW	diffusion weighted
E-M	expectation maximization
EGFR	epidermal growth factor receptor
EI	exposure index
EM	electromagnetic
EORTC	European Organization for Research and Treatment of Cancer

ER	estrogen receptor
ESAK	entrance surface air kerma
ESF	edge spread function
EW	evanescent wave
fat-sat	fat saturated
FCC	fibrocystic change
FD	frequency domain
FDG	fluorodeoxyglucose (^{18}F)
FDM	finite-difference method
fDOT	fluorescence diffuse optical tomography
FDTD	finite-difference time domain
FEM	finite-element method
FES	fluoro-17β-estradiol
FFDM	full-field digital mammography
FG	fibroglandular
FG	fractal geometry
FLDA	Fisher linear discriminant analysis
FN	false negative
FNA	fine-needle aspiration
FNAC	fine-needle aspiration cytology
FNN	false nearest neighbor
FP	false positive
FROC	free-response ROC
FS	feature selection
FUI	feature usability index
GLCM	gray-level co-occurrence matrix
GMM	Gaussian mixture model
GSDF	grayscale standard display function
GUI	graphical user interface
H&E	hematoxylin-eosin
HCC	hepatocellular carcinoma
HC-PCF	hollow-core photonic crystal fiber
HC/UFPE	Clinical Hospital of the Federal University of Pernambuco
HIFU	high-intensity focused ultrasound
HL7	health level 7
HNG	high nuclear grade
HRT	hormone replacement therapy
HSP	heat shock protein
HVL	half-value layer
IAEA	International Atomic Energy Agency
ICG	indocynanine-green
IDC	invasive ductal carcinoma

IFN	interferon
IG-NIRS	image-guided NIR spectroscopy
IM	internal mammary
ING	intermediate nuclear grade
IR	infrared
ITK	Insight Toolkit
IV	intravenous
JAFROC	jackknife alternative free-response ROC
JND	just-noticeable difference
k-NN	*k*-nearest neighbor
LA	laser ablation
LBP	local binary pattern
LC-VCO	inductor/capacitor voltage-controlled oscillator
LCIS	lobular carcinoma *in situ*
LE	Lyapunov exponent
LNG	low nuclear grade
LSM	least-square method
LTB	lesion-to-background (ratio)
LUT	lookup table
MCC	microcalcification
MD	mid-density
MGD	mean glandular dose
MGH	Massachusetts General Hospital
MIAS	Mammographic Image Analysis Society
MIP	maximum-intensity projection
MIPT	maximum-intensity projection over time
mIPT	mean-intensity projection over time
ML	maximum likelihood
MOF	microstructured optical fiber
MPV	mean pixel value
MQSA	Mammography Quality Standards Act
MR	magnetic resonance
MRI	magnetic resonance imaging
MRS	magnetic resonance spectroscopy
MTAI	microwave-induced thermoacoustic imaging
MTF	modulation transfer function
MWA	microwave ablation
MWI	microwave imaging
NADH	nicotinamide adenine dinucleotide plus hydrogen
NBC	Naïve Bayesian classifier
NICE	National Institute for Health and Clinical Excellence (UK)
NIR	near infrared

NPV	negative predictive value
OI	optical index
OO	object-oriented (model)
ORD	object-relational database
PASH	pseudo-angiomatous stromal hyperplasia
PBG	photonic bandgap
PBS	phosphate-buffered saline
PCF	photonic crystal fiber
PD	progressive disease
PEM	positron emission mammography
PET	positron emission tomography
PET-CT	PET with computed tomography
PDU	power Doppler ultrasound
PHA	phytohaemagglutinin
PMMA	poly(methyl methacrylate)
PMT	photomultiplier tube
PNN	probabilistic neural network
PO	pulse oximeter
PPIX	protoporphyrin IX
PPV	positive predictive value
PR	partial response
PR	progesterone receptor
QA	quality assurance
QAP	quality assurance program
QC	quality control
QDA	quadratic discriminant analysis
RBF	radial basis function
RECIST	response evaluation criteria in solid tumors
RF	radiofrequency
RFA	radiofrequency ablation
RI	refractive index
RI	resistivity index
ROC	receiver operating characteristic
ROI	region of interest
ROL	reference operating level
RPS	reconstructed phase space
S/C	signal-to-clutter ratio
SD	stable disease
SDNR	signal-difference-to-noise ratio
SEM	scanning electron microscope
SFM	screen-film mammography
SI	shape index
SID	source-to-image distance

SHH	Sacred Heart Hospital
SIRT	simultaneous iterative reconstruction technique
SLNB	sentinel lymph node biopsy
SMPTE	Society of Motion Picture and Television Engineers
SNR	signal-to-noise ratio
SPAD	single-photon avalanche diode
SPECT	single-photon emission computed tomography
SQP	sequential quadratic programming
std	standard deviation
STIR	short tau inversion recovery
StO_2	tissue oxygenation or oxygen saturation
SUVmax	maximum standardized uptake value
SUVmean	mean standardized uptake value
SVD	singular value decomposition
SVM	support vector machine
TBS	tris-buffered saline
TBST	tris-buffered saline/Tween
TD	time domain
TDE	time-delay embedding
TDLU	terminal ductalobular unit
THC	total haemoglobin concentration
THI	tissue harmonic imaging
TIL	tumor-infiltrating lymphocyte
TN	true negative
TNF	tumor necrosis factor
TP	true positive
TPSF	temporal point spread function
TS	time series
TSFC	texture shape feature coding
UCI	University of California Irvine
US	ultrasound/ultrasonography
US NCI	United States National Cancer Institute
USPIO	ultrasmall superparamagnetic iron oxide
UWB	ultrawideband
VAB	vacuum-assisted biopsy
VOI	volume of interest
WB	whole body
WDBC	Wisconsin Diagnostic Breast Cancer (database)
WFUSM	Wake Forest University School of Medicine
WHO	World Health Organization
WU	Washington University in St. Louis