Electronic Imaging Applications in Mobile Healthcare
Electronic Imaging Applications in Mobile Healthcare

Jinshan Tang
Sos S. Agaian
Jindong Tan
Editors

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Preface

Information technology is changing healthcare systems in revolutionary ways; there can be no health care reform without an information revolution. One information technology that is transforming healthcare systems is mobile technology. As it develops and matures, mobile technology is having a significant impact on healthcare, and emerging mobile technologies are attracting significant attention as well as investment of time and effort among researchers and industrial developers. The combination of mobile technology with healthcare has produced an important research area called mHealth. In 2011, U.S. Secretary of Health and Human Services, Kathleen Sebelius, referred to mHealth as “the biggest technology breakthrough of our time” and maintained that its use would “address our greatest national challenge.” Based on related research, mobile health is projected to be a 26 billion dollar industry by 2017.

Mobile technology has wide-ranging applications in human healthcare, such as monitoring elderly patients, security access control for electronic health records, and remote radiology. The primary drivers behind these applications are varied, as evidenced by the following facts:

- Current mobile computing devices already offer many advanced features, such as high-quality cameras, web searching, sound recording, and global positioning systems (GPS).¹
- The capabilities of mobile computing devices (mobile tablet devices and smartphones) are growing.
- The implementation of mobile imaging platform/systems is growing. Currently, thousands of apps are available, including apps for disease diagnosis, diet and disease tracking, medication and exercise planning, and blood pressure monitoring.
- A growing number of physicians are recognizing the advantages of using mobile tools.
- The mobile technologies in current use are already providing new opportunities by boosting communication between different healthcare
providers and between healthcare providers and patients, and by allowing access to medical images from virtually any location.

In fact, a 2012 study by Manhattan Research discovered that approximately 62% of U.S. doctors utilize some type of tablet device in their practice, nearly doubling the adoption rate since 2011.\textsuperscript{2}

According to industry evaluations, 500 million smartphone users worldwide will be using a healthcare application by 2018, and 50% of the more than 3.4 billion smartphone and tablet users will have downloaded mobile health applications.\textsuperscript{3} Moreover, the Food and Drug Administration (FDA) “recognizes the extensive variety of actual and potential functions of mobile apps, the rapid pace of innovation in mobile apps, and the potential benefits and risks to public health represented by these apps.”\textsuperscript{4} Finally, mobile computing devices have become commonplace in healthcare settings, leading to rapid growth in the development of biomedical software applications for these platforms.\textsuperscript{5,6}

The aim of this book is to publish state-of-the-art research in electronic imaging technologies as applied to mobile healthcare, and to promote research in mHealth. The twelve chapters in this book are organized into four parts:

Part I deals with image processing and enhanced visualization. Chapter 1 introduces image processing techniques for mobile healthcare systems. Chapter 2 presents image enhancement technology for low-vision patients who use mobile devices to see images. Chapter 3 describes the application of fast Fourier transform-based methods for color medical imaging in mobile devices. Chapter 4 presents new quaternion-based image enhancement tools that can be used as a preprocessing step in conventional cell phone imaging systems by improving the interpretability of information in images for phone viewers. Chapter 5 develops an adapted retinex algorithm for medical image enhancement using mobile phones.

Part II deals with security issues in mobile healthcare applications. Chapter 6 examines security issues for mobile devices using cloud services and presents a homomorphic encryption method that enables direct operation over the encoded data and hence facilitates complete privacy protection. Chapter 7 proposes a novel and fast encryption of images and their decryption without loss of information for medical image viewing on a cell phone.


Part IV includes three chapters on mobile healthcare applications. Chapter 10 deals with skin cancer monitoring with an iPhone using image retrieval techniques. Chapter 11 presents a user interface for mobile
healthcare. Finally, Chapter 12 presents an automatic multiview food classification method for a food intake assessment system on a smartphone. We hope that this book will inspire further research in mHealth.

Jinshan Tang  
Sos S. Agaian  
Jindong Tan  
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References


5. S. Wallace, M. Clark, and J. White, “‘It’s on my iPhone:’ Attitudes to the use of mobile computing devices in medical education, mixed-methods study,” BMJ Open 2(4), e001099 (2012).

List of Contributors

Sos S. Agaian
The University of Texas at San Antonio, San Antonio, Texas USA

David Akopian
The University of Texas at San Antonio, San Antonio, Texas, USA

Rafayel Barseghyan
Institute for Informatics and Automation Problems of the National Academy of Sciences of Armenia

Mahadevan Gomathisankaran
Microsoft Corporation, Redmond, Washington, USA

Artyom M. Grigoryan
The University of Texas at San Antonio, San Antonio, Texas, USA

Yanliang Gu
Michigan Technological University, Houghton, Michigan, USA

Hongsheng He
University of Tennessee, Knoxville, Tennessee, USA

Wei Hu
Wuhan University of Science and Technology, Wuhan, China and Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan, China

Zilong Hu
Michigan Technological University, Houghton, Michigan, USA

Sahak Kaghyan
Institute for Informatics and Automation Problems, National Academy of Sciences of Armenia

Gevorg Karapetyan
Institute for Informatics and Automation Problems of the National Academy of Sciences of Armenia

Fanyu Kong
Google, Inc., New York, New York, USA

Jun Liu
Wuhan University of Science and Technology, Wuhan, China and Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan, China

Xiaoming Liu
Wuhan University of Science and Technology, Wuhan, China and...
List of Contributors

Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan, China

**Jafet Morales**  
The University of Texas at San Antonio, San Antonio, Texas, USA

**Fahao Qiao**  
Michigan Technological University, Houghton, Michigan, USA

**Hollie A. Raynor**  
University of Tennessee, Knoxville, Tennessee, USA

**Hakob Sarukhanyan**  
Institute for Informatics and Automation Problems of the National Academy of Sciences of Armenia

**Jindong Tan**  
University of Tennessee, Knoxville, Tennessee, USA

**Jinshan Tang**  
Michigan Technological University, Houghton, Michigan, USA

**Bryan Wiatrek**  
The University of Texas at San Antonio, San Antonio, Texas, USA

**Xiaohui Yuan**  
University of North Texas, Denton, Texas, USA

**Kai Zhang**  
Wuhan University of Science and Technology, Wuhan, China and Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan, China

**Daikun Zou**  
Wuhan University of Science and Technology, Wuhan, China and Hubei Province Key Laboratory of Intelligent Information Processing and Real-time Industrial System, Wuhan, China
# Acronyms and Abbreviations

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<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>A-GPS</td>
<td>Assisted Global Positioning System</td>
</tr>
<tr>
<td>ADT</td>
<td>Android Development Tools</td>
</tr>
<tr>
<td>AES</td>
<td>Advanced Encryption Standard</td>
</tr>
<tr>
<td>AF</td>
<td>Auto-focus</td>
</tr>
<tr>
<td>API</td>
<td>Application Programming Interface</td>
</tr>
<tr>
<td>BPM</td>
<td>Beats per minute</td>
</tr>
<tr>
<td>BSS</td>
<td>Blind Source Separation</td>
</tr>
<tr>
<td>CA</td>
<td>Certificate Authority</td>
</tr>
<tr>
<td>CBIR</td>
<td>Content-Based Image Retrieval</td>
</tr>
<tr>
<td>CFS</td>
<td>Correlation-Based Feature Selection</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
</tr>
<tr>
<td>DCT</td>
<td>Discrete Cosine Transform</td>
</tr>
<tr>
<td>DES</td>
<td>Data Encryption Standard</td>
</tr>
<tr>
<td>DFT</td>
<td>Discrete Fourier Transform</td>
</tr>
<tr>
<td>DICOM</td>
<td>Digital Imaging and Communications in Medicine</td>
</tr>
<tr>
<td>DMP</td>
<td>Digital Motion Processor</td>
</tr>
<tr>
<td>DoG</td>
<td>Difference of Gaussian</td>
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<tr>
<td>DR</td>
<td>Diabetic Retinopathy</td>
</tr>
<tr>
<td>DSA</td>
<td>Digital Signature Algorithm</td>
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<tr>
<td>DT</td>
<td>Decision Table</td>
</tr>
<tr>
<td>DTr</td>
<td>Decision Tree</td>
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<tr>
<td>DT-CWT</td>
<td>Dual-Tree Complex Wavelet Transform</td>
</tr>
<tr>
<td>DT-RCWF</td>
<td>Dual-Tree Rotated Complex Wavelet Filter</td>
</tr>
<tr>
<td>DTW</td>
<td>Dynamic Time Warping</td>
</tr>
<tr>
<td>DUT</td>
<td>Discrete Unitary Transform</td>
</tr>
<tr>
<td>DWT</td>
<td>Discrete Wavelet Transform</td>
</tr>
<tr>
<td>ECG</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>EKG</td>
<td>Electrocardiogram</td>
</tr>
<tr>
<td>E-OTD</td>
<td>Enhanced Observed Time Difference</td>
</tr>
<tr>
<td>FDA</td>
<td>Food and Drug Administration (U.S.)</td>
</tr>
<tr>
<td>FIR</td>
<td>Finite Impulse Response</td>
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<tr>
<td>FISH</td>
<td>Fluorescence <em>in situ</em> Hybridization</td>
</tr>
</tbody>
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FFT
fast Fourier transform
FPS
frames per second
GDC
great common divisor
GPS
global positioning system
GPU
graphics processing unit
GSM
Global System for Mobile communications
HAR
human activity recognition
HD
high definition
HF
heart failure
HIS
Hospital Information System
HOG
histogram of oriented gradient
HMM
hidden Markov model
HR
heart rate
HSV
hue-saturation-value
ICA
independent component analysis
ICT
information and communication technology
IDE
integrated development environment
IDFT
inverse discrete Fourier transform
IIR
infinite impulse response
INS
inertial navigation system
iOS
iPhone operating system
JVM
Java virtual machine
kNN
$k$-nearest neighbor
LAN
local area network
LBP
local binary pattern
MEMS
micro-electromechanical system
mHealth
mobile health
MRI
magnetic resonance imaging
MSER
maximally stable extremal regions
MSR
multiscale retinex
MSR-CR
multiscale retinex color restoration
MST
minimum spanning tree-based (method)
NB
naïve Bayes
NDK
Native Development Kit (Android)
OCT
optical coherence tomography
OHMD
optical head-mounted display
OTDOA
observed time difference of arrival
PACS
picture archiving and communication system
PC
personal computer
PCA
principal component analysis
PDA
personal digital assistant
PDR
Physician’s Desk Reference
PFE
$p$-Fibonacci encryption
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>PFID</td>
<td>Pittsburg Fast-food Image Dataset</td>
</tr>
<tr>
<td>PKI</td>
<td>public key infrastructure</td>
</tr>
<tr>
<td>PPG</td>
<td>photoplethysmography</td>
</tr>
<tr>
<td>PSDQ</td>
<td>preprocessed signal data-holder queue</td>
</tr>
<tr>
<td>QDFT</td>
<td>quaternion discrete Fourier transform</td>
</tr>
<tr>
<td>RAM</td>
<td>random access memory</td>
</tr>
<tr>
<td>RMIS</td>
<td>remote medical information system</td>
</tr>
<tr>
<td>RMSE</td>
<td>root mean square error</td>
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<tr>
<td>RNS</td>
<td>residue number system</td>
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<tr>
<td>ROI</td>
<td>region of interest</td>
</tr>
<tr>
<td>RSA</td>
<td>Rivest, Shamir, Adleman (developers of the cryptographic algorithm called RSA)</td>
</tr>
<tr>
<td>RSDQ</td>
<td>raw signal data-holder queue</td>
</tr>
<tr>
<td>SD</td>
<td>secure digital (card)</td>
</tr>
<tr>
<td>SDK</td>
<td>Software Development Kit (Android)</td>
</tr>
<tr>
<td>SIFT</td>
<td>scale-invariant feature transform</td>
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<tr>
<td>SMC</td>
<td>secure multiparty computation</td>
</tr>
<tr>
<td>SNR</td>
<td>signal-to-noise ratio</td>
</tr>
<tr>
<td>SSR</td>
<td>single-scale retinex</td>
</tr>
<tr>
<td>SVM</td>
<td>support vector machine</td>
</tr>
<tr>
<td>UI</td>
<td>user interface</td>
</tr>
<tr>
<td>USB</td>
<td>universal serial bus</td>
</tr>
<tr>
<td>WLAN</td>
<td>wireless local area network</td>
</tr>
<tr>
<td>WMA</td>
<td>weighted moving average</td>
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