Chapter 15
Medical Imaging

Ge Wang
Virginia Tech, USA

Jie Zhang
University of Minnesota, USA

Alex Cong
Virginia Tech, USA

Victor J. Weir
Baylor Health Care System, USA

Hao Gao
University of California-Los Angeles, USA

Xiaochen Xu
Texas Instruments, USA

James Bennett
Virginia Tech, USA

ABSTRACT

Medical imaging is both an indispensable tool and a highly interdisciplinary field. Over the past decades, progress in medical imaging theory and technology has dramatically accelerated. This chapter provides a comprehensive study of the fundamental and advanced principles behind each of the major imaging modalities. It also presents topics related to the vision of the future of each modality. The chapter is intended for upper level or graduate biomedical engineering/bioengineering/medical physics students, researchers, and faculty.

15.1. CHAPTER OBJECTIVES

Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), Ultrasound (US) and optical imaging are independent research areas; each of them generates numerous scans and papers annually, and deserves several books for comprehensive coverage. Instead of presenting all the technical subtleties and application details, the objectives of this chapter (for each of the aforementioned) modalities are as follows:

- Present the fundamental ideas and principles in an *"engineer friendly"* language, specifically for senior undergraduate and graduate students in the field of Biomedical Engineering.

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- Describe the most important imaging methods, representative system architectures and illustrative clinical applications so that students, researchers and administrators can make educated judgments in career planning, research collaboration and management.
- Discuss major research directions to promote relevant research, foster interdisciplinary collaboration, and induce forward thinking; this will be facilitated through a comprehensive list of key references at the end of this chapter.

15.2. INTRODUCTION

Civilization has been driven by the need for extending human capabilities, including *visual perception*. Our native vision is limited by many factors, one of which is the opaqueness of many objects like our bodies. It is a fascinating idea to have *"an inner vision"*, like a comic book character. In the last century, x-ray computed tomography (CT) gained prevalence as the first tomographic imaging modality that produced an accurate, non-destructive image of an object via x-ray measurement. Subsequently, other different tomographic imaging modalities were developed including: MRI, PET, SPECT, US, optical imaging, etc. These modalities utilize different physical principles, reveal diagnostic information from complementary perspectives, and can be integrated into tremendous synergies.

Modern imaging technologies can be categorized into three generations: i) anatomical/structural imaging (e.g., x-ray CT quantifies tumor sizes), ii) functional imaging (e.g., functional MRI of the brain), and iii) molecular imaging (e.g., PET-CT studies, fluorescence and bioluminescence tomography). The *NIH Roadmap* (http://commonfund.nih.gov) presents a number of major initiatives to accelerate medical research. The Molecular Libraries and Imaging (http://commonfund.nih.gov/molecularlibraries/index.aspx) initiative suggests new ways for imaging of cellular and molecular features in biologic systems on multiple scales – from single cells to whole organisms. One goal is to improve detection sensitivity 10- to-100-fold, for a wide range of diseases and functions. Clearly, imaging tools are instrumental for modern medicine, and promise to be predictive, preventive, personalized and participatory.

According to www.bharatbook.com, in 2009 the American market for medical imaging equipment was estimated at over $8.5 billion, in spite of the 2007-2008 global economic recession. In 2011, Global Industry Analysts (GIA, Inc., http://www.StrategyR.com) released a comprehensive report on the global market for three-dimensional (3D) medical imaging equipment that was forecast to reach $3.5 billion by 2015. The driving factors include: an aging developed-world population, critical diseases, new applications (e.g., cardiology and dentistry), technological advancements, and developing markets. For example, Asia is a rapidly developing continent where biomedical imaging R&D has shown great progress, with a yearly market growth of about 30%, in China.

15.3. A COMPREHENSIVE DEFINITION OF MEDICAL IMAGING

Medical imaging is defined as the field of studies on the theories, methods, techniques and systems that non-invasively produce images of internal structures of the human body. Modern medical imaging demands innovative solutions to inverse problems, as the key is to non-invasively obtain information about internal features. Imaging should avoid harm to the subject, and maintain the biological processes under investigation intact. A wide portion of the electrical and magnetic spectrum is utilized by various medical imaging modalities (Table 1). Some modalities provide a fairly direct means to produce an image (e.g.,