Computed Tomography
Principles, Design, Artifacts, and Recent Advances
THIRD EDITION
Computed Tomography
Principles, Design, Artifacts, and Recent Advances

THIRD EDITION

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Preface

X-ray computed tomography (CT) has experienced a tremendous explosion in technological development over the last quarter century, a phenomenon rarely seen in industry. Few could have predicted the speed, magnitude, and duration of the progress. The third edition of *Computed Tomography* captures the most recent advances in technology and clinical applications.

This third edition provides significant additions in several areas. The first area of major enhancement is on the topic of iterative reconstruction. With the heightened awareness of radiation dose in CT in recent years, iterative reconstruction has evolved from a topic in academic research to the mainstream of CT reconstruction for all commercially available scanners. Chapter 3 describes the fundamental concept of iterative reconstruction, the idea of statistical reconstruction, methodologies used to model CT systems, and searching methodologies for optimal solutions. Given the clinical demands on workflow, a brief discussion on the reconstruction speedup effort is also provided.

One complexity brought by the iterative reconstruction technology is performance evaluation. Unlike the filtered backprojection reconstruction algorithm, in general, iterative reconstruction performance is nonlinear. Although some of the existing measurement approaches are still useful, they are inadequate to fully assess the performance of iteratively reconstructed images. Chapter 5 has an added section that discusses the impact and various measurement methodologies of iterative reconstruction.

Historically, the presentation of the CT outcome has been limited to computer monitors, either at scanner consoles, workstations, or PACS monitors. With the recent advancements in 3D printing, however, physical models can be quickly prototyped to convey CT information. Therefore, a section was added in Chapter 4 to introduce approaches by the early adopters in the area.

In terms of radiation dose, the topic of a size-specific dose estimate (SSDE) has been added. During the last few years, significant attention has been paid to the radiation impact on human health by academic researchers, radiologists, the general public, and the news media. Although awareness on the subject has been increasing, dose measurement methodology was
developed more than a decade ago. The updated Chapter 11 briefly describes
the recent proposal of a dose measurement index, SSDE, in an attempt to
more accurately reflect the dose absorption rates of specific-sized patients, and
proposed modifications to the dose measurement for scanners with large z
coverage.

When the second edition of this book was published, true cone-beam CT
had just been introduced commercially. Nowadays, scanners capable of
single-organ coverage in a rotation are widely available commercially and
have significantly impacted clinical practices. Chapter 10 has been expanded
to discuss the technological challenges associated with wide-cone step-and-
shoot reconstruction and the additional challenges with cardiac imaging.

Dual-energy CT was predominately in the hands of a few researchers at
the time of the second edition publication. The situation has significantly
changed since then, as dual-energy CT is now utilized in routine clinical
applications to aid in disease diagnosis. A significant expansion to Chapter 12
has been written to provide the technology background, theoretical
development, and clinical applications of dual-energy CT.

To enhance readers’ understanding of the material and to inspire creative
thinking about the topics presented, more problems have been added at the
end of each chapter. Many problems are open-ended and may not have
uniquely correct solutions.

At the time of the publication of the second edition, the world was
experiencing an unprecedented financial crisis that some called a financial
“tsunami.” Although we predicted that “CT technology is unlikely to remain
stagnant,” nobody was certain about the true impact the crisis would have on
CT development. Recent advances in CT have shown that the entire industry
remains healthy, and the demand for advanced CT technologies has expanded
beyond the developed counties. The future of CT remains bright.

Acknowledgments

Many of the ideas, principles, results, and examples that appear in this book
stem from thoughts provoked by other books and research papers, and the
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Nomenclature and Abbreviations

AAPM  American Association of Physicists in Medicine
ACR   American College of Radiology
ALARA as low as reasonably achievable
ART   algebraic reconstruction technique
ASIC  application-specific integrated circuit
BMD   bone mineral density
bpm   beats per minute (heart rate)
CAC   coronary artery calcification
CAI   coronary artery imaging
CAT   computer-aided tomography
CBF   cerebral blood flow
CBV   cerebral blood volume
CDRH  Center for Devices and Radiological Health (FDA)
CG    conjugate gradient
COPD  chronic obstructive pulmonary disease
CT    computed tomography
CTDI  CT dose index
DAS   data acquisition system
DECT  dual-energy CT
DFT   discrete Fourier transform
DLP   dose–length product
DSP   digital signal processing
EBCT  electron-beam computed tomography
EBT   electron-beam tomography
EC    European Commission
ECG/EKG electrocardiogram
FBP   filtered backprojection
FDA   US Food and Drug Administration
FDK   Feldkamp–Davis–Kress (cone-beam reconstruction algorithm)
FFR   fractional flow reserve
FFT   fast Fourier transform
<table>
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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>FOV</td>
<td>field of view</td>
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<tr>
<td>FWHM</td>
<td>full width at half maximum</td>
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<tr>
<td>FWTM</td>
<td>full width at tenth maximum</td>
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<td>GDE</td>
<td>geometric detection efficiency</td>
</tr>
<tr>
<td>GPU</td>
<td>graphic processor unit</td>
</tr>
<tr>
<td>Gy</td>
<td>grays (a unit used to measure absorbed radiation dose)</td>
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<tr>
<td>HCT</td>
<td>helical computed tomography</td>
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<tr>
<td>HU</td>
<td>Hounsfield unit</td>
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<tr>
<td>IAC</td>
<td>inner auditory canal</td>
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<td>IAEA</td>
<td>International Atomic Energy Agency</td>
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<tr>
<td>ICD</td>
<td>iterative coordinate decent</td>
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<tr>
<td>ICRP</td>
<td>International Commission on Radiological Protection</td>
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<td>IFFT</td>
<td>inverse fast Fourier transform</td>
</tr>
<tr>
<td>IR</td>
<td>iterative reconstruction</td>
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<tr>
<td>kerma</td>
<td>kinetic energy released to matter</td>
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<tr>
<td>LCD</td>
<td>low-contrast detectability</td>
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<td>LSF</td>
<td>line spread function</td>
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<td>MBIR</td>
<td>model-based iterative reconstruction</td>
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<td>minMIP</td>
<td>minimum intensity projection</td>
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<tr>
<td>MIP</td>
<td>maximum intensity projection</td>
</tr>
<tr>
<td>MPR</td>
<td>multiplanar reformation</td>
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<tr>
<td>MSAD</td>
<td>multiple-scan average dose</td>
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<tr>
<td>MTF</td>
<td>modulation transfer function</td>
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<tr>
<td>MTT</td>
<td>mean transit time</td>
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<td>NPS</td>
<td>noise power spectrum</td>
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<tr>
<td>OS</td>
<td>ordered subset</td>
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<tr>
<td>PET</td>
<td>positron emission (computed) tomography</td>
</tr>
<tr>
<td>PSF</td>
<td>point spread function</td>
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<tr>
<td>QA</td>
<td>quality assurance</td>
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<tr>
<td>QDE</td>
<td>quantum detection efficiency</td>
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<tr>
<td>rad</td>
<td>radiation absorbed dose (a basic unit of absorbed dose of ionizing radiation)</td>
</tr>
<tr>
<td>RCA</td>
<td>right coronary artery</td>
</tr>
<tr>
<td>rem</td>
<td>Roentgen equivalent man (a unit used to measure the amount of damage to human tissue from ionizing radiation)</td>
</tr>
<tr>
<td>ROC</td>
<td>receiver operating characteristics</td>
</tr>
<tr>
<td>ROI</td>
<td>region of interest</td>
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<tr>
<td>SPECT</td>
<td>single-photon-emission computed tomography</td>
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<tr>
<td>SSDE</td>
<td>size-specific dose estimate</td>
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<tr>
<td>SSP</td>
<td>slice sensitivity profile</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Definition</td>
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<tr>
<td>Sv</td>
<td>sieverts (a unit used to measure the effect of radiation on the human body)</td>
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<tr>
<td>TAT</td>
<td>transverse axial tomography</td>
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<tr>
<td>VR</td>
<td>volume rendering</td>
</tr>
<tr>
<td>WL</td>
<td>(display) window level</td>
</tr>
<tr>
<td>WW</td>
<td>(display) window width</td>
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