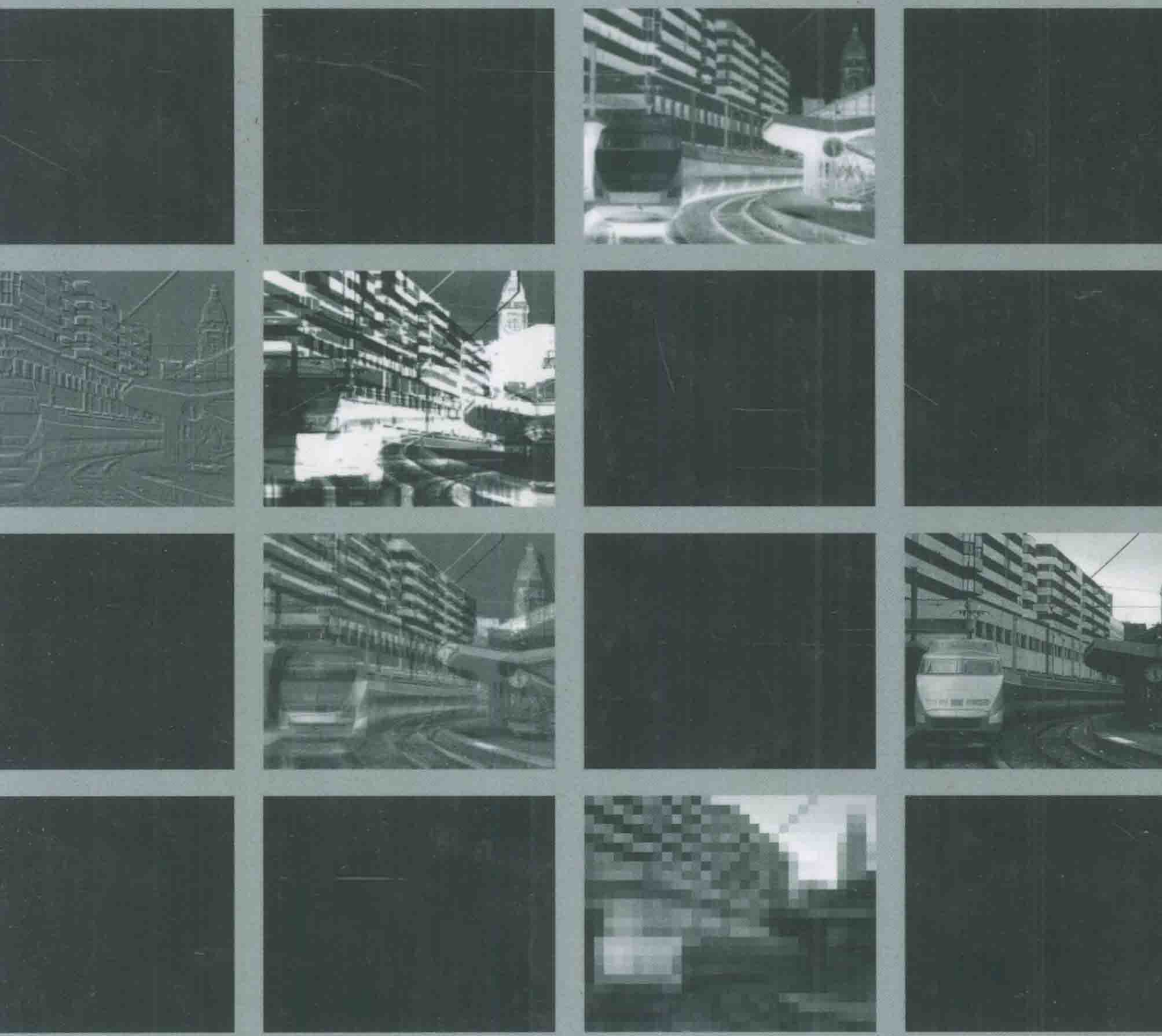

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SIGNAL PROCESSING and PERFORMANCE ANALYSIS for IMAGING SYSTEMS

Signal Processing and Performance Analysis for Imaging Systems

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Signal Processing and Performance Analysis for Imaging Systems

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To our families

Preface

In today's consumer electronics market where a 5-megapixel camera is no longer considered state-of-the-art, signal and image processing algorithms are real-time and widely used. They stabilize images, provide super-resolution, adjust for detector nonuniformities, reduce noise and blur, and generally improve camera performance for those of us who are not professional photographers. Most of these signal and image processing techniques are company proprietary and the details of these techniques are never revealed to outside scientists and engineers. In addition, it is not necessary for the performance of these systems (including the algorithms) to be determined since the metric of success is whether the consumer likes the product and buys the device.

In other imaging communities such as military imaging systems (which, at a minimum, include visible, image intensifiers, and infrared) and medical imaging devices, it is extremely important to determine the performance of the imaging system, including the signal and image processing techniques. In military imaging systems that involve target acquisition and surveillance/reconnaissance, the performance of an imaging system determines how effective the warfighter can accomplish his or her mission. In medical systems, the imaging system performance determines how accurately a diagnosis can be provided. Signal and image processing plays a key role in the performance of these imaging systems and, in the past 5 to 10 years, has become a key contributor to increased imaging system performance. There is a great deal of government funding in signal and image processing for imaging system performance and the literature is full of university and government laboratory developed algorithms. There are still a great number of industry algorithms that, overall, are considered company proprietary. We focus on those in the literature and those algorithms that can be generalized in a nonproprietary manner.

There are numerous books in the literature on signal and image processing techniques, algorithms, and methods. The majority of these books emphasize the mathematics of image processing and how they are applied to image information. Very few of the books address the overall imaging system performance when signal and image processing is considered a component of the imaging system. Likewise, there are many books in the area of imaging system performance that consider the optics, the detector, and the displays in the system and how the system performance behaves with changes or modifications of these components. There is very little book content where signal and imager processing is included as a component of the overall imaging system performance. This is the gap that we have attempted to fill with this book. While algorithm development has exploded in the past 5 to 10 years, the system performance aspects are relatively new and not quite fully understood. While the focus of this book is to help the scientist and engineer begin to understand that these algorithms are really an imaging system component and help in the system performance prediction of imaging systems with these algorithms, the performance material is new and will undergo dramatic improvements in the next 5 years.

We have chosen to address signal and image processing techniques that are not new, but the real time implementation in military and medical systems are relatively new and the performance predication of systems with these algorithms are definitely new. There are some algorithms that are not addressed such as electronic stabilization and turbulence correction. There are current programs in algorithm development that will provide great advances in algorithm performance in the next few years, so we decided not to spend time on these particular areas.

It is worth mentioning that there is a community called "computational imaging" where, instead of using signal/image processing to improve the performance of an existing imaging system approach, signal processing is an inherent part of the electro-optical design process for image formation. The field includes unconventional imaging systems and unconventional processing, where the performance of the collective system design is beyond any conventional system approach. In many cases, the resulting image is not important. The goal of the field is to maximize system task performance for a given electro-optical application using nonconventional design rules (with signal processing and electro-optical components) through the exploitation of various degrees of freedom (space, time, spectrum, polarization, dynamic range, and so forth). Leaders in this field include Dennis Healey at DARPA, Ravi Athale at MITRE, Joe Mait at the Army Research Laboratory, Mark Mirotznick at Catholic University, and Dave Brady at Duke University. These researchers and others are forging a new path for the rest of us and have provided some very stimulating experiments and demonstrations in the past 2 or 3 years. We do not address computational imaging in this book, as the design and approach methods are still a matter of research and, as always, it will be some time before system performance is addressed in a quantitative manner.

We would like to thank a number of people for their thoughtful assistance in this work. Dr. Patti Gillespie at the Army Research Laboratory provided inspiration and encouragement for the project. Rich Vollmerhausen has contributed more to military imaging system performance modeling over the past 10 years than any other researcher, and his help was critical to the success of the project. Keith Krapels and Jonathan Fanning both assisted with the super-resolution work. Khoa Dang, Mike Prarie, Richard Moore, Chris Howell, Stephen Burks, and Carl Halford contributed material for the fusion chapter. There are many others who worked signal processing issues and with whom we collaborated through research papers to include: Nicole Devitt, Tana Maurer, Richard Espinola, Patrick O'Shea, Brian Teaney, Louis Larsen, Jim Waterman, Leslie Smith, Jerry Holst, Gene Tener, Jennifer Parks, Dean Scribner, Jonathan Schuler, Penny Warren, Alan Silver, Jim Howe, Jim Hilger, and Phil Perconti. We are grateful for the contributions that all of these people have provided over the years.

We (S. Susan Young and Eddie Jacobs) would like to thank our coauthor, Dr. Ronald G. Driggers for his suggestion of writing this book and encouragement in this venture. Our understanding and appreciation of system performance significance started from collaborating with him. S. Susan Young would like to thank Dr.

Hsien-Che Lee for his guidance and help early in her career in signal and image processing. On a personal side, we authors are very thankful to our families for their support and understanding.

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PART I

Basic Principles of Imaging Systems and Performance

CHAPTER 1

Introduction

1.1 "Combined" Imaging System Performance

The "combined" imaging system performance of both hardware (sensor) and software (signal processing) is extremely important. Imaging system hardware is designed primarily to form a high-quality image from source emissions under a large variety of environmental conditions. Signal processing is used to help highlight or extract information from the images that are generated from an imaging system. This processing can be automated for decision-making purposes or it can be utilized to enhance the visual acuity of a human looking through the imaging system.

Performance measures of an imaging system have been excellent methods for better design and understanding of the imaging system. However, the imaging performance of an imaging system with the aid of signal processing has not been widely considered in the light of improving image quality from imaging systems and signal processing algorithms. Imaging systems can generate images with low-contrast, high-noise, blurring, or corrupted/lost high-frequency details, among others. How does the image performance of a low-cost imaging system with the aid of signal processing compare with the one of an expensive imaging system? Is it worth investing in higher image quality by improving the imaging system hardware or by developing the signal processing software? The topic of this book is to relate the ability of extracting information from an imaging system with the aid of signal processing to evaluate the overall performance of imaging systems.

1.2 Imaging Performance

Understanding the image formation and recording process helps in understanding the factors that affect image performance and therefore helps the design of imaging systems and signal processing algorithms. The image formation process and the sources of image degradation, such as loss of useful high-frequency details, noise, or low-contrast target environment, are discussed in Chapter 2.

Methods of determining image performance are important tools in determining the merits of imaging systems and signal processing algorithms. Image performance determination can be performed via subjective human perception studies or image performance modeling. Image performance prediction and the role of image performance modeling are also discussed in Chapter 3.