Design and Implementation of **Autostereoscopic Displays**

Tutorial Texts Series

- *Design Technology Co-optimization in the Era of Sub-resolution IC Scaling*, Lars W. Liebmann, Kaushik Vaidyanathan, and Lawrence Pileggi, Vol. TT104
- *Special Functions for Optical Science and Engineering*, Vasudevan Lakshminarayanan and L. Srinivasa Varadharajan, Vol. TT103
- *Discrimination of Subsurface Unexploded Ordnance*, Kevin A. O'Neill, Vol. TT102
- *Introduction to Metrology Applications in IC Manufacturing*, Bo Su, Eric Solecky, and Alok Vaid, Vol. TT101
- *Introduction to Liquid Crystals for Optical Design and Engineering*, Sergio Restaino and Scott Teare, Vol. TT100
- *Design and Implementation of Autostereoscopic Displays*, Byoungho Lee, Soon-gi Park, Keehoon Hong, and Jisoo Hong, Vol. TT99
- *Ocean Sensing and Monitoring: Optics and Other Methods*, Weilin Hou, Vol. TT98
- *Digital Converters for Image Sensors*, Kenton T. Veeder, Vol. TT97
- *Laser Beam Quality Metrics*, T. Sean Ross, Vol. TT96
- *Military Displays: Technology and Applications*, Daniel D. Desjardins, Vol. TT95
- *Interferometry for Precision Measurement,* Peter Langenbeck, Vol. TT94
- *Aberration Theory Made Simple, Second Edition*, Virendra N. Mahajan, Vol. TT93
- *Modeling the Imaging Chain of Digital Cameras*, Robert D. Fiete, Vol. TT92
- *Bioluminescence and Fluorescence for* In Vivo *Imaging*, Lubov Brovko, Vol. TT91
- *Polarization of Light with Applications in Optical Fibers*, Arun Kumar and Ajoy Ghatak, Vol. TT90
- *Digital Fourier Optics: A MATLAB Tutorial*, David G. Voeltz, Vol. TT89
- *Optical Design of Microscopes*, George Seward, Vol. TT88
- *Analysis and Evaluation of Sampled Imaging Systems*, Richard H. Vollmerhausen, Donald A. Reago, and Ronald Driggers, Vol. TT87
- *Nanotechnology: A Crash Course*, Raúl J. Martin-Palma and Akhlesh Lakhtakia, Vol. TT86
- *Direct Detection LADAR Systems*, Richard Richmond and Stephen Cain, Vol. TT85
- *Optical Design: Applying the Fundamentals*, Max J. Riedl, Vol. TT84
- *Infrared Optics and Zoom Lenses, Second Edition*, Allen Mann, Vol. TT83
- *Optical Engineering Fundamentals, Second Edition*, Bruce H. Walker, Vol. TT82
- *Fundamentals of Polarimetric Remote Sensing*, John Schott, Vol. TT81
- *The Design of Plastic Optical Systems*, Michael P. Schaub, Vol. TT80
- *Fundamentals of Photonics*, Chandra Roychoudhuri, Vol. TT79
- *Radiation Thermometry: Fundamentals and Applications in the Petrochemical Industry*, Peter Saunders, Vol. TT78
- *Matrix Methods for Optical Layout*, Gerhard Kloos, Vol. TT77
- *Fundamentals of Infrared Detector Materials*, Michael A. Kinch, Vol. TT76
- *Practical Applications of Infrared Thermal Sensing and Imaging Equipment, Third Edition*, Herbert Kaplan, Vol. TT75
- *Bioluminescence for Food and Environmental Microbiological Safety*, Lubov Brovko, Vol. TT74
- *Introduction to Image Stabilization*, Scott W. Teare and Sergio R. Restaino, Vol. TT73
- *Logic-based Nonlinear Image Processing*, Stephen Marshall, Vol. TT72
- *The Physics and Engineering of Solid State Lasers*, Yehoshua Kalisky, Vol. TT71
- *Thermal Infrared Characterization of Ground Targets and Backgrounds, Second Edition*, Pieter A. Jacobs, Vol. TT70
- *Introduction to Confocal Fluorescence Microscopy*, Michiel Müller, Vol. TT69
- *Artificial Neural Networks: An Introduction*, Kevin L. Priddy and Paul E. Keller, Vol. TT68
- *Basics of Code Division Multiple Access (CDMA),* Raghuveer Rao and Sohail Dianat, Vol. TT67
- *Optical Imaging in Projection Microlithography*, Alfred Kwok-Kit Wong, Vol. TT66
- *Metrics for High-Quality Specular Surfaces*, Lionel R. Baker, Vol. TT65
- *Field Mathematics for Electromagnetics, Photonics, and Materials Science*, Bernard Maxum, Vol. TT64
- *High-Fidelity Medical Imaging Displays*, Aldo Badano, Michael J. Flynn, and Jerzy Kanicki, Vol. TT63

(For a complete list of Tutorial Texts, see http://spie.org/tt.)

Design and Implementation of **Autostereoscopic Displays**

Byoungho Lee
Soon-gi Park
Keehoon Hong
Jisoo Hong

Tutorial Texts in Optical Engineering
Volume TT99

SPIE PRESS
Bellingham, Washington USA

Library of Congress Cataloging-in-Publication Data

Names: Lee, Byoungho, author. | Park, Soon-gi, 1986- author. | Hong, Keehoon, 1983- author. | Hong, Jisoo, 1981- author.
Title: Design and implementation of autostereoscopic displays / Byoungho Lee, Soon-gi Park, Keehoon Hong, and Jisoo Hong.
Other titles: Tutorial texts in optical engineering ; v. TT 99.
Description: Bellingham, Washington : SPIE, [2016] | ?2016 | Series: Tutorial texts in optical engineering ; volume TT 99 | Includes bibliographical references and index.
Identifiers: LCCN 2015035678 | ISBN 9781628416800 (alk. paper) | ISBN 1628416807 (alk. paper)
Subjects: LCSH: Three-dimensional display systems.
Classification: LCC TK7882.T47 L44 2015 | DDC 621.3815/422—dc23 LC record available at http://lccn.loc.gov/2015035678

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

Printed in the United States of America.
First printing.

SPIE.

Introduction to the Series

Since its inception in 1989, the Tutorial Texts (TT) series has grown to cover many diverse fields of science and engineering. The initial idea for the series was to make material presented in SPIE short courses available to those who could not attend and to provide a reference text for those who could. Thus, many of the texts in this series are generated by augmenting course notes with descriptive text that further illuminates the subject. In this way, the TT becomes an excellent stand-alone reference that finds a much wider audience than only short course attendees.

Tutorial Texts have grown in popularity and in the scope of material covered since 1989. They no longer necessarily stem from short courses; rather, they are often generated independently by experts in the field. They are popular because they provide a ready reference to those wishing to learn about emerging technologies or the latest information within their field. The topics within the series have grown from the initial areas of geometrical optics, optical detectors, and image processing to include the emerging fields of nanotechnology, biomedical optics, fiber optics, and laser technologies. Authors contributing to the TT series are instructed to provide introductory material so that those new to the field may use the book as a starting point to get a basic grasp of the material. It is hoped that some readers may develop sufficient interest to take a short course by the author or pursue further research in more advanced books to delve deeper into the subject.

The books in this series are distinguished from other technical monographs and textbooks in the way in which the material is presented. In keeping with the tutorial nature of the series, there is an emphasis on the use of graphical and illustrative material to better elucidate basic and advanced concepts. There is also heavy use of tabular reference data and numerous examples to further explain the concepts presented. The publishing time for the books is kept to a minimum so that the books will be as timely and up-to-date as possible. Furthermore, these introductory books are competitively priced compared to more traditional books on the same subject.

When a proposal for a text is received, each proposal is evaluated to determine the relevance of the proposed topic. This initial reviewing process has been very helpful to authors in identifying, early in the writing process, the need for additional material or other changes in approach that would serve to strengthen the text. Once a manuscript is completed, it is peer reviewed to ensure that chapters communicate accurately the essential ingredients of the science and technologies under discussion.

It is my goal to maintain the style and quality of books in the series and to further expand the topic areas to include new emerging fields as they become of interest to our reading audience.

James A. Harrington
Rutgers University

Table of Contents

Preface

Since the early 2000s, flat-panel displays have advanced exponentially in both multi-user and personal applications. Color expression and the resolution of images provided by the state-of-the-art displays are beyond the perceptible range of human eyes and virtually indistinguishable from the real world. However, display technologies can go further to provide an immersive and realistic experience. In order to achieve those goals, a three-dimensional (3D) expression of a display is an essential factor because we live in a 3D world and perceive it as 3D information.

3D displays are beneficial compared to two-dimensional (2D) displays because the process of observing images is more similar to the natural experience than that of 2D displays. However, the technological limitation of 3D displays limits the popularity of 3D display applications. Current applications of 3D displays are mostly focused on the entertainment area such as movies and games due to the fixed viewing positions of observers or the use of viewing aids and the ease of generating 3D contents using computer-graphics technologies rather than picking up 3D images from real objects. If the viewing conditions of 3D images and acquisition techniques of 3D information are developed enough, we can expect many other 3D display applications in addition to entertainment applications. A 3D video call or 3D teleconference can be good examples. Virtual reality (VR) or augmented reality (AR) can also have more effects on real-life applications with 3D displays. Moreover, a 3D visualization of scientific results in medical, biological, or other technological fields will be beneficial to academic analysis and education. 3D displays will be also helpful for industrial development. The prototyping of a product will be accelerated, and the training of employees will be done much more effectively with 3D displays. Consequently, many applications that currently use 2D displays may potentially use 3D displays instead.

For those purposes, one of the barriers that current 3D displays must overcome is glasses. Glasses-free, or autostereoscopic, displays provide perspectives of images according to the position of an observer. For providing perspectives, various optical elements are used in autostereoscopic systems. Although autostereoscopic technologies encompass various display technologies, a multi-view-based method is the current mainstream of 3D displays

because of its compatibility with flat-panel displays. This book introduces various autostereoscopic technologies from the fundamental principles of the parallax barrier method to the latest multi-projection super-multi-view displays.

The beginning chapters explain the process of the observation of 3D images from a light source to an observer. In the real world, light emitted from a source is reflected or scattered at an object, collected by eyes and, perceived as an object. The observation of 3D images through a 3D display includes more steps: capturing, processing, and display. Instead of directly observing a real object, the information is captured by an imaging device and processed, then it is reconstructed by a 3D display. For those new to display technology, the overall background of 3D display technologies is introduced in Chapter 1. Chapters 2 and 3 focus on directional-view-based 3D displays, including multi-view and integral imaging displays. The practical guide to fabrication of each display system is provided for understanding of the basic principle of each display method. Chapter 4 deals with the acquisition of 3D information from computer graphics and real objects using an optical method. Later chapters cover further details of multi-view technologies and introduce recently reported advanced 3D display technologies.

Possible readers of this book range from undergraduate students to display manufacturers in the industry. Display basics and fundamentals of 3D displays can be a practical guide to those who do not have any background knowledge of display technologies. Examples of multi-view systems will help readers understand the configuration of basic 3D display systems. For readers with some previous knowledge of 3D display technologies, detailed explanations are also provided for advanced display technologies, such as the slanted lens technique and multi-projection systems. The References will be helpful for further study.

We tried our best to cover a wide range of autostereoscopic displays from its conceptual beginning to recent research. Because the technological advancements of conventional 2D displays affect the development of 3D displays, we also tried to cover the basics of 2D displays, including flat panel displays as well as projection-type displays. We believe that this book will help readers improve their comprehension of autostereoscopic displays. We hope that our book contributes to more active research on autostereoscopic 3D displays to realize a world of 3D displays in the near future.

We appreciate the effort of our supporters for the publication of this book. We thank Dr. James A. Harrington for his suggestion and support of the publication. We also thank SPIE staff Tim Lamkins, Tyler Koshakow, and, especially, Dara Burrows for their helpful advice, encouragement, and copyediting efforts. We acknowledge the support of our colleagues in the Optical Engineering and Quantum Electronics Laboratory, Seoul National

University. Jae-Hyun Jung, Jiwoon Yeom, Chang-Kun Lee, Jonghyun Kim, Jinsoo Jeong, Changwon Jang, Youngmo Jeong, Jong-Young Hong, and Matheus Miranda helped us with researching a wide range of background technologies, illustrating conceptual diagrams of technologies, and the fabrication of example systems. The writing of this book is based on our long-term study. We especially acknowledge recent support by the IT R&D program of MSIP/KEIT (fundamental technology development for digital holographic contents) and The Cross-Ministry Giga KOREA Project (Development of Super Multi-View (SMV) Display Providing Real-Time Interaction) of The Ministry of Science, ICT and Future Planning, Korea.

Byoungho Lee
Soon-gi Park
Keehoon Hong
Jisoo Hong
December 2015