Introduction to
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STABILIZATION
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Introduction to

IMAGE STABILIZATION

Scott W. Teare
Sergio R. Restaino

Tutorial Texts in Optical Engineering
Volume TT73

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Introduction to the Series

Since its inception in 1989, the Tutorial Texts (TT) series has grown to more than 80 titles covering 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 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
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Preface

The use of image stabilization has grown to the point that it is now a common component of modern optical systems for imaging, communications, and remote sensing applications. The benefits of image stabilization to astronomical research alone are so rich that it is common for astronomical telescopes, built over the last century, to be retrofitted with fast steering mirrors and tip-tilt sensors to extend their useful lifetimes. Some of these telescopes also incorporate more advanced adaptive optics systems to improve their performance to near the diffraction limit in spite of the effects of the atmosphere.

While the benefits of image stabilization are well appreciated, most scientists and engineers have little exposure to the technology and basic principles. This text aims at providing the basics of image stabilization starting with a consideration of the cause of image blurring, and an introduction to the components commonly used in constructing a stabilized imaging system. With this foundation, an example of an image stabilized system is described and used to introduce some of the important parameters in evaluating the performance of image stabilization systems. As image stabilization systems are key components of adaptive optics systems, we touch briefly on the more sophisticated sensing and correction devices used in this area.

It is our hope that Introduction to Image Stabilization provides the interested reader with a useful overview of this topic and will provide the impetus for moving on to more advance texts on image stabilization and adaptive optics. This book is not meant to be a mathematical, rigorous treatment of image stabilization, but is meant to provide the basic ideas in an easy-to-read format.

Chapter 1 provides a general discussion about image stabilization, the wavefront, beam wander, and image jitter. Chapter 2 provides an overview of the effects of atmospheric turbulence on a wavefront, and Chapters 3 and 4 discuss how to sense and minimize these effects, respectively. In Chapter 5, the devices introduced in the previous two chapters are combined into an image-stabilization system, with Chapter 6 discussing key performance issues of such systems. Chapter 7 provides a brief survey of existing image-stabilization systems. Chapter 8 describes several alternative approaches to image stabilization that, while less common, can also be effective. Complete coverage of all possible approaches and methods available for image stabilization is not possible in an introductory text, so the authors have focused on the most commonly encountered approaches. Also, many of the subtleties of advanced image-stabilization systems have been left for the interested reader to
explore on his/her own. References to many useful articles and texts are provided in Chapter 9.

Many individuals contributed to the writing of this book both directly and indirectly and we are grateful for their contributions. We would particularly like to thank Jonathan Andrews and Christopher Wilcox, Naval Research Laboratory, for many useful discussions and their efforts in preparing some of the graphics and reviewing the text. Of course, the errors that remain in the text are our responsibility to correct and we would be grateful for any comments or corrections. Please send them to the authors, c/o New Mexico Tech, Department of Electrical Engineering, Socorro, NM 87801 USA.

The technology and devices used in image stabilization have been evolving rapidly over the years and we keenly appreciate our colleagues and collaborators who have generously provided their time to engage in technical discussions with us. We are very grateful to Jeff Baker, Baker Adaptive Optics; Alan Greenaway, Heriot-Watt University; Don Payne, Narrascape; Ty Martinez, Naval Research Laboratory; Laird Thompson, University of Illinois at Urbana-Champaign; Gleb Vdovin, Delft University of Technology; and David V. Wick, Sandia National Laboratories; for sharing their insights over the years. We apologize if we have inadvertently left anyone off this list, but sincerely appreciate the help of all our colleagues.

We are grateful for the support of SPIE for their interest in publishing this work in the Tutorial Text Series and Merry Schnell, our editor, for bringing this work to its final form.

Scott W. Teare and Sergio R. Restaino
New Mexico, 2006
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