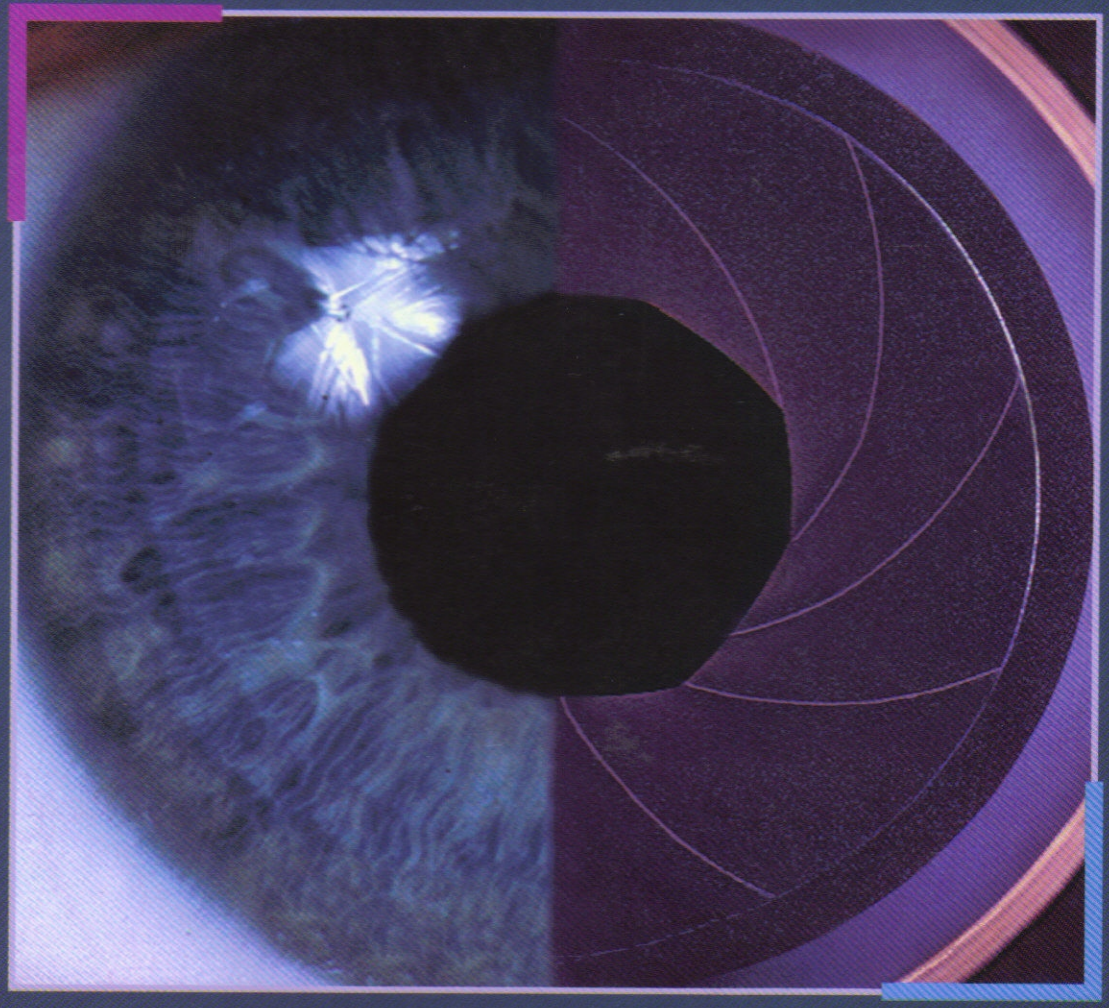
MACHINE VISION



Ramesh Jain • Rangachar Kasturi • Brian G. Schunck

MACHINE VISION

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MACHINE VISION

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Ramesh is a Fellow of IEEE, AAAI, and Society of Photo-Optical Instrumentation Engineers, and member of ACM, Pattern Recognition Society, Cognitive Science Society, Optical Society of America, and Society of Manufacturing Engineers. He is currently the Editor-in-Chief of *IEEE Multimedia,* and is on the editorial boards of *Machine Vision and Applications, Pattern Recognition,* and *Image and Vision Computing.* He received his Ph.D. from IIT, Kharagpur, in 1975 and his B.E. from Nagpur University in 1969.

Rangachar Kasturi joined Penn State University in 1982 after completing his graduate studies at Texas Tech University (Ph.D. 1982 and M.S.E.E. 1980). He received a B.E. (Electrical) degree from Bangalore University in 1968. His primary research focus in recent years has been in the area of Document Image Analysis (DIA). His group's main contribution has been the

design of efficient algorithms to generate intelligent interpretations of engineering drawings and maps to facilitate automatic conversion from paper medium to computer databases. He is the Editor-in-Chief of *IEEE Transactions on Pattern Analysis and Machine Intelligence.* He was the managing editor of *Machine Vision and Applications* during 1993–94. He is a coauthor of the tutorial texts, *Computer Vision: Principles and Applications* and *Document Image Analysis,* both published by IEEE CS Press, and a coeditor of the book *Image Analysis Applications* (Marcel Dekker, 1990). During 1987–90 he delivered lectures at many chapters of the IEEE Computer Society through its Distinguished Visitor Program. He has served the International Association for Pattern Recognition in various capacities.

Brian G. Schunck has worked for several years on the development of systems for machine vision and image processing. He was educated in computer science at the University of California, Irvine, where he received the B.S. magna cum laude in 1976. He studied electrical engineering, systems theory, and artificial intelligence at M.I.T., where he received the Master's and E.E. degrees in 1979 for work on control algorithms for robotic manipulators and the doctorate in 1983 for research on image flow. He was an assistant professor in the Department of Electrical Engineering and Computer Science and a member of the Artificial Intelligence Laboratory at the University of Michigan, Ann Arbor. Currently he is the Director of Vision Software at Adept Technology.

Brian's current interests include statistical methods for machine vision and industrial inspection; contour, surface, and volume models for computer vision and medical image processing; structure and motion estimation for mobile robots; reverse engineering part models from range data; computer graphics; user interfaces; and marine navigation.

Brian Schunck is a member of the IEEE, ACM, the Society for Industrial and Applied Mathematics, the American Statistical Association, the American Society for Photogrammetry and Remote Sensing, the Society for Manufacturing Engineers, and the Society for Automotive Engineers.

To

Sudha

—*Ramesh Jain*

My Grandmother

—*Rangachar Kasturi*

Gizmo

—*Brian G. Schunck*

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Preface

This book grew out of our efforts to provide a balanced coverage of essential elements of machine vision systems to students in our undergraduate and early graduate classes. The field of machine vision, or computer vision, has been growing at a fast pace. The growth in this field, unlike most established fields, has been both in breadth and depth of concepts and techniques. To make the situation more confusing, the number of new applications has also been growing. Machine vision techniques are being applied in areas ranging from medical imaging to remote sensing, industrial inspection to document processing, and nanotechnology to multimedia databases.

As in most developing fields, not all aspects of machine vision that are of interest to active researchers are useful to the designers of a vision system for a specific application. A designer needs to know basic concepts and techniques to be successful in designing or evaluating a vision system for a particular application. It may not be necessary to know the latest, often controversial, results from leading research centers. On the other hand, the techniques learned by a designer should not be ephemeral.

This text is intended to provide a practical introduction to machine vision. We made efforts to provide all of the details to allow vision algorithms to be used in practical applications. Intentionally omitted are theories of machine vision that do not appear to have sufficient practical applications at this time. We want this to be a useful introduction to machine vision rather than a state-of-the-art collection of research on machine vision.

The text is intended to be used in an introductory course in machine vision at the undergraduate or early graduate level and should be suitable for students with no prior knowledge of computer graphics or signal processing. Students should have a working knowledge of mathematics through calculus of two variables, including matrices and linear spaces, and familiarity with basic probability theory, computer programming, and elementary data structures. Numerical and statistical methods and advanced algorithms are described as needed as well as material on geometry in two and three dimensions. For some sections in the book, more mathematical background is needed. Such sections can be omitted by readers not interested in the rigorous formalization. We have made efforts to provide intuitive concepts, even for mathematical sections, that will help a reader understand the basic elements without the details.

An introductory text is based on material from several sources. This book also contains material from research papers, books, and other places. We have made no attempt to exhaustively list all original sources. We do provide some pointers to readers who are interested in exploring topics more deeply in each chapter. The references at the end of the book provide a list of sources that were directly used in the preparation of the book.

We strongly encourage readers to send any comments and corrections by mail to one of the authors or electronically to jain@ece.ucsd.edu.

Ramesh Jain
Rangachar Kasturi
Brian G. Schunck

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Numerous students directly contributed to the preparation of this book. The most important help and contributions came from David Kosiba. David helped us in all aspects of the book, including many of the illustrations and the concept for the cover art. This book has been influenced significantly by his energy, interest in machine vision, and perseverance. Sue Lott and Dino Terzides also helped with the illustrations. Other students who went out of their way to provide help included Sandy Bartlett, James Han, Patrick Kelly, Dan Sebald, Nilesh Patel, Francis Quek, Todd Elvins, Arun Katkere, Saied Moezzi, and Jennifer Schlenzig. We sincerely appreciate the secretarial support provided by Suzie Mostoller at Penn State, Kathy Dewitt at

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