HANDBOOK OF PATTERN RECOGNITION & COMPUTER VISION

(2nd Edition)

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HANDBOOK OF PATTERN RECOGNITION & COMPUTER VISION

(2nd Edition)

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PREFACE TO THE SECOND EDITION

The progress in pattern recognition and computer vision since the publication of the first edition in 1993 has been enormous. While the first edition is never out of date, to incorporate new activities in the field, and to incorporate many valuable comments by the readers of the first edition, it is useful now to present a new edition. More than half of the pages of this volume are new, reporting a number of new activities. This edition also contains five parts: (1) Basic Methods in Pattern Recognition, (2) Basic Methods in Computer Vision, (3) Recognition Applications, (4) Inspection and Robotic Applications, and (5) Architectures and Technology, with a total of 34 chapters of original work on various topics.

Part 1 starts with a chapter on cluster analysis which is followed by a chapter on statistical recognition and a chapter on syntactic pattern recognition. Until about twenty years ago, these three areas are what fundamental pattern recognition was about. The re-discovery of artificial neural networks in the mid-eighties has made it an essential topic of modern pattern recognition. The fourth chapter addresses particularly neural network computing from the viewpoint of implementing pattern recognition algorithms. Additional basic pattern recognition methods are presented in the next two chapters on Gaussian Markov random field model and 3-D object pattern representation respectively. The first two chapters of Part 2 deal with texture analysis and segmentation. We agree with some readers' comments that the first edition placed a lot emphasis on texture analysis and in fact Chapters 1.5; 2.1; 2.2; 4.2 of this edition are texture-based. This reflects that more progress has been made on this topic. The third chapter on color in computer vision has been fully rewritten from the first edition to provide some latest progress. The next two chapters are on projective geometry and 3-D motion analysis. The last two chapters of Part 2 present aspects of 3-D shape representation and 3-D surface-based systems.

Part 3 provides a comprehensive study of nine recognition applications including: nondestructive testing of materials, speech recognition, remote sensing application, fingerprint processing using an opto-electronic system, human chromosomes classification, document processing, biomedical signal recognition, geographic data analysis, and face recognition. Obviously it is not possible to present all application areas and the readers are kindly requested to refer to the first edition and other publications for additional recognition applications. The first two chapters of Part 4 are in fish industry inspection and textured surface inspection with industrial objects. The next chapter on context related issues in image understanding is of concern to all inspection and robotic applications. The chapter on computer vision in postal automation represents one aspect of robotic application. The last

chapter on vision-based automatic vehicle guidance presents an area of emerging importance in intelligent transportation systems and again robotic vision can play an important role. Part 5 deals with several aspects of architecture and technological development. The first chapter on vision provides a tutorial discussion of technological issues in computer vision. The next chapter presents highlights of optical pattern recognition. Infrared imagery technology has been around for some time and its application has not been limited to military and medical areas. The third chapter deals with this technology and its use in classification problems. Another major technological development is the video content analysis and retrieval which is discussed in the fourth chapter. The VLSI architecture for computing central moments for pattern recognition and image processing is presented in the final chapter with applications to breast cancer detection and road pavement distress detection. We understand that even with all chapters in this volume, there are still a lot of activities in pattern recognition and computer vision not presented here. Our view is that a handbook is not a dictionary and it is not desirable to cover all topics superficially. The in-depth treatment of a topic in each chapter can provide readers with a good understanding on the subject while collectively the chapters capture well all major developments in this field.

The second edition is specially dedicated to the memory of Professor King Sun Fu. There are five chapters written by Professor Fu's former students. During his career, Professor Fu has approached almost every area of recognition application in his time. By following his emphasis on applications, we have expanded the application part considerably. We are fortunate to have Professor Azriel Rosenfeld, who knew Professor Fu well, to write on the topic of vision with some speculations. Professor Rosenfeld's words of wisdom will always be helpful to the research and education community. We are also fortunate to have Professor C. C. Li, who was Professor Fu's classmate at the National Taiwan University, to prepare a memorial article. We thank both of them for their contributions.

We like to take this opportunity to express our deep gratitude to all new and old contributors to this handbook series. This volume continues to represent the most comprehensive and most up to date handbook publication in pattern recognition and computer vision. The book will certainly help us to prepare for a new century of dynamic development in this field.

The co-editors

June 1998

PREFACE

The area of pattern recognition and computer vision, after over 35 years of continued development, has now reached its maturity. The theories, techniques and algorithms are mostly well developed. There are a number of applications which are still being explored. New approaches motivated by applications and new computer architectures available are still being studied. Also the recently renewed and intensive efforts on neural networks have had great and positive impact on pattern recognition and computer vision development. Pattern recognition and computer vision will definitely play a very major role in advanced automation as we enter the 21st century.

Amid all of these activities now going on, this new *Handbook of Pattern Recognition and Computer Vision* is much needed to cover what has been well developed in theory, techniques and algorithms and the major applications of pattern recognition and computer vision as well as the new hardware/architecture aspects of computer vision and the related development in pattern recognition. The previous *Handbook of Pattern Recognition and Image Processing*, edited by T. Y. Young and the late K. S. Fu (Academic Press, 1986) was well received. The progress in pattern recognition and computer vision has been particularly significant in the recent past. We believe this new handbook that reflects more recent developments especially in computer vision will serve well the increasingly larger community of readers in the area. As students and friends of Prof. Fu, we remember well his vigorous efforts to broaden the frontiers of pattern recognition and computer vision in both theories and applications, to build it as an interdisciplinary area, and to lay down the foundation of intelligent and automated systems based on pattern recognition and computer vision. The book, in keeping up with his vision for the area, provides an extensive coverage of major research progress since the publication of Young and Fu's book.

The book is organized into five parts. Part 1 presents a thorough coverage of the basic methods in pattern recognition including clustering techniques, statistical pattern recognition, neural network computing, feature selection, and syntactic, structural and grammatical pattern recognition. Part 2 presents comprehensively the basic methods in computer vision including texture image analysis and model based segmentation, color and geometrical tools, 3-D motion analysis, mathematical morphology, and parallel thinning algorithms. Part 3 presents several major pattern recognition applications in nondestructive evaluation, geophysical signal interpretation, economics and business, underwater signals, character recognition and document understanding, biomedical image recognition and medical image

understanding. Part 4 focuses on unique applications in inspection and robotics with topics on computer vision in the food processing industry, context modeling and position estimation for robots, and related issues. Part 5, on the other hand, examines the broader system aspects, including designing computer vision systems, optical pattern recognition, spatial knowledge representation, neural network architecture for image segmentation, architectures for computer vision and image information systems. More than 85 per cent of the chapters are original and unpublished work while the remaining reprint chapters provide complementary coverage.

There is no doubt that a single volume handbook like this cannot examine every aspect of pattern recognition and computer vision, nor can it present the contributions of all leading researchers. However, we believe the book has captured both the scope and depth of progress in this highly dynamic and multidisciplinary area. In preparing the book, we are most fortunate to bring together all contributors who are among the leaders in the area. We would like to take this opportunity to express our deep gratitude to their unselfish and timely efforts to share their expertise with the readers. We also like to thank Dr. K. K. Phua and Ms. Jennifer Gan of World Scientific Publishing for their help and encouragement throughout the preparation of this volume.

C. H. Chen
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September 1992

FOREWORD

VISION: SOME SPECULATIONS

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1. Introduction

The purpose of vision is to extract useful information about the world from images. Computer vision attempts to do this by computer analysis of digitized images. Efforts along these lines have been under way for over 40 years; but even the domains first studied in the 1950s (which included handwriting, photomicrographs of biological specimens, and aerial photographs of built-up areas) still present many unsolved problems. This very brief note presents some comments, many of them intended to be provocative, about the reasons for the slow progress in the field and the ways in which successes are likely to be achieved.

2. Vision and Mathematics

As an homage to Wigner [1], this section might have been entitled “On the unsurprising ineffectiveness of mathematics in the visual sciences”. Most vision problems, even those that were first tackled in the 1950s, are mathematically ill-defined (reading handwritten words, counting cells, recognizing buildings). Real-world visual domains do not satisfy simple mathematical (even probabilistic) models. Even when such models are assumed, problems that involve inferring information about a scene from images are often mathematically ill-posed or computationally intractable; but a more serious difficulty is that the models themselves are unrealistic, and are likely to remain so for a long time to come [2].

On a more positive note, mathematical and statistical tools do have their uses in formulating vision problems; in particular, they provide methods of describing image formation processes and image analysis algorithms. There also exist domains (typically involving machine-made scenes: printed documents, integrated circuits, mechanical arts, all with controlled lighting) that can be mathematically modelled quite accurately (as long as the scene is not too dirty!). In these sorts of domains, vision systems can be designed to perform quite successfully, provided they take the model seriously and bring adequate computer power to bear on the task.

3. Vision and Biology

In this section we put mathematics aside and consider what might be called the “multilegged existence theorems” for vision [3]. Animals use vision quite effectively in the real world. Apparently, simple algorithms can be quite useful for extracting useful information about natural environments (for example [4], insects rarely collide with the underbrush even when flying through it at many body lengths per second); though an organism may have trouble coping if its environment changes significantly (for example, a frog surrounded by unmoving flies will probably starve to death [5]). Simple computer vision algorithms can in fact be designed, sometimes with the aid of learning techniques, that will usually perform usefully in real-world environments; but they may fail disastrously if they encounter unusual situations.

For simple organisms, nature overcomes their individual limitations by providing large populations in which there are variations among the individuals. Thus even if many individuals fail, others survive (or learn to survive) and may pass their successful characteristics on to their descendants. (It has been suggested, half-seriously, that this might provide a biological justification for the hundreds of “yet another...” computer vision algorithms in the literature; but note that the analogy is valid only if these algorithms are compared on a variety of tasks, so their potential advantages can be discovered!) Only a few pieces of research are truly innovative and can be regarded as major mutations; as in nature, such breakthroughs are sometimes lethal, but they may sometimes succeed in producing new successful species of vision systems. This “biological” approach could be used to discover useful computer vision algorithms through extensive experiments with real data; but it does not seem practical to develop robot vision systems in this way, since the cost of the failures would probably be unacceptable. A possible strategy for developing useful vision algorithms, without incurring many costly failures, might be to initially use large sets of recorded real-world data to design and test the algorithms.

Higher-level organisms are more flexible in their uses of vision. Their flexibility may be based on an ability to evaluate and combine the information extracted from the images in multiple visual “areas” or “pathways”. This suggests that computer vision systems could benefit from the deliberate use of multiple techniques — an approach that has been generally avoided in the past because of its computational cost.

Another possible basis for the successful visual performance(s) of organisms is that they make use of redundant visual data. Computer vision systems often try to reduce computational cost by analyzing only single (sets of) frames, and (for dynamic scenes) using results obtained from earlier frames as predictors to simplify the analysis of later frames. Biological organisms, on the other hand, process all the data that their visual systems provide (though results obtained from earlier processing may serve to direct attention to subsets of the results obtained from later processing). The availability of redundant data allows an organism to discover

processing errors, since they give rise to results that are not persistent. Computer vision systems are just reaching the levels of processing power that will allow them to handle, in real time, amounts of input data comparable to those handled by biological visual systems, and to apply multiple processing techniques to the data. As these levels are reached, vision system performance may significantly improve.

4. Concluding Remarks

Over the past four decades, the performance of computer vision systems has largely kept pace with available computer power. Many domains remain intractable from a theoretical standpoint, but systems that take advantage of data and algorithm redundancy may eventually achieve performances comparable to those of biological organisms, which serve as living demonstrations of the effectiveness of vision in the real world.

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- [2] A. Rosenfeld, Some thoughts about image modeling, In K. V. Mardia and G. K. Kanji, (eds.), *Statistics and Images 1* (Advances in Applied Statistics, Supplement to J. Appl. Stat. 20 (5/6), Carfax Pub. Co., Abingdon, Oxfordshire, UK, 1993) 19–22.
- [3] R. A. Kirsch (personal communication, June 1967) used the phrase “two-legged existence theorem” as an argument for the feasibility of computer vision (or, as we were calling it then, “pictorial pattern recognition”). He probably had in mind only featherless bipeds, but an even earlier example (an existence proof for the air-to-ground ATR problem) is Skinner’s 1945 demonstration that pigeons could be trained to serve as effective bombsights.
- [4] J. A. Albus, personal communication, about 1990.
- [5] J. Y. Lettvin, H. R. Maturana, W. S. McCulloch and W. H. Pitts, What the frog’s eye tells the frog’s brain, *Proc. Ire* **47** (1959) 1940–1957.

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A MEMORIAL TO THE LATE PROFESSOR KING-SUN FU

Twelve years have gone by since the passing away of Professor King-Sun Fu, an eminent scholar and a pioneer in the field of pattern recognition, computer vision, and machine intelligence. This volume is dedicated to his memory by his friends and students as a testimonial to his profound and enduring influence. I am honored to be asked to write a memorial article. Here I will give a biography* of King-Sun as well as a short addendum to the bibliography of his published works compiled in 1985.

King-Sun was born on October 2, 1930, in Nanking, China, the second son of his parents, General and Mrs. Tzao-Jen Fu. The Fu family's native city, however, is Hangzhou, Zhejiang. He pursued his middle school education at the Chinese Air Force Youth Preparatory School. After his father died in 1949, his mother took him and two younger brothers to Taiwan, where he matriculated in the National Taiwan University in the Fall of 1949. He was one of the top students in the Electrical Engineering Department. Not only did he excel in mathematics and engineering subjects, but he also cultivated interests in classical music and literature. Perhaps the latter pursuit laid the foundation for his own prolific writing in serial journals and scientific books. His writing was distinct: clearly expressive and succinct. The demands of academia did not serve to stifle his personal exuberance and vitality in life, however, and, in finding a balance to his studies, King-Sun was also active on the basketball and volleyball teams in the school. He was indeed a versatile student on the campus.

After graduating from the National Taiwan University with a B.S.E.E. degree in 1953 and completing one year of ROTC training, King-Sun received a graduate assistantship from the Electrical Engineering Department of the University of Toronto, Canada, and went there in September 1954 to start his graduate study. He wrote his master's degree thesis on dynamic analysis of large electric machines and received his M.A.Sc. degree in the summer of 1955.

In September 1955 he transferred to the University of Illinois, Urbana, IL, USA, for his doctoral study in Electrical Engineering, and completed his Ph.D. dissertation in network theory on "An Approximation Method for Both Magnitude and Phase by Rational Functions" in February 1959 under Professor M. E. Van Valkenburg. During his three and a half years at the University of Illinois, King-Sun became immensely interested in statistical methods, information theory, abstract algebra, and modern analysis. He was a top student in Professor J. L. Doob's course

*Portions of the biography are reprinted, with permission, from IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. PAMI-8, No. 3, pp. 291-294, May 1996. © 1986 IEEE.

on stochastic processes which was intended for mathematics graduate students only. This extraordinary background paved the way for his later research in sequential methods of statistical pattern recognition and machine learning. On the Urbana campus, King-Sun fell in love with Miss Viola Ou, then a graduate student in library science. They were married in Urbana, Illinois, on April 7, 1958.

After receiving his Ph.D. degree from the University of Illinois in 1959, King-Sun worked for a year and a half as a research engineer at Boeing Airplane Company, Seattle, Washington, from February 1959 to August 1960. He also taught as a special lecturer at the Seattle University during the Spring Semester of 1960. In September 1960 he accepted a faculty position at Purdue University, West Lafayette, Indiana, as an assistant professor in the School of Electrical Engineering. The following semester he was selected by Purdue to be a visiting scientist with the Research Laboratory of Electronics at Massachusetts Institute of Technology from February to June 1961. During that summer he was with the IBM Thomas J. Watson Research Center at Yorktown Heights, NY. After he returned to Purdue University in September 1961, he began to pursue his research in pattern recognition and machine intelligence — a field in which he played a prominent role in its development during the next quarter of a century. He became an associate professor in September 1963 and was promoted to the rank of professor of electrical engineering in September 1966. In 1967 he was a visiting professor of electrical engineering and computer science at the University of California, Berkeley. He was the assistant head for research at the School of Electrical Engineering at Purdue from 1969 to 1972. In 1972 he was awarded a prestigious Guggenheim fellowship and was a visiting professor of electrical engineering at both Stanford University and the University of California, Berkeley. After returning to Purdue, he established the Advanced Automation Research Laboratory in the School. He was named the Goss Distinguished Professor of Engineering at Purdue University in 1975. During the Fall of 1984 he, along with other colleagues at Purdue, initiated the highly innovative program of research in intelligent manufacturing. This program resulted in the start-up of the National Science Foundation Engineering Research Center for Intelligent Manufacturing Systems during early 1985. King-Sun was the founding director of the Center. At the peak of his career, his sudden death in April 1985 was a tremendous loss to our scientific and engineering community.

During the earlier years he first focused his study on statistical pattern recognition and learning systems. From 1961 to 1970 he and his students developed sequential methods for feature selection and pattern recognition, non-parametric procedures for pattern classification, a stochastic approximation approach to learning control systems, and stochastic and learning automata. His first research monograph entitled “Sequential Methods in Pattern Recognition and Machine Learning” was published in 1968. By the late 1960’s he began his unique research on syntactic pattern recognition, which was introduced by the earlier efforts of Murray Eden, R. Narasimhan, R. A. Kirsch, Robert S. Ledley, and Alan Shaw. King-Sun initiated and launched in-depth studies on stochastic context-free

programmed languages and stochastic syntax analysis for pattern recognition and image analysis.

His book, "Syntactic Methods in Pattern Recognition", was published in 1974. In the ensuing years he and his students made the greatest and foremost impact on syntactic pattern recognition research. His school developed fundamental methodologies of stochastic error-correcting syntax analysis, error-correcting parsers for formal languages and, in particular, for attributed and stochastic tree grammars, and error-correcting isomorphisms of attributed relational graphs for pattern recognition. The syntactic methods for texture analysis, shape recognition, and image modeling were introduced in the late 1970's, and the three-dimensional plex grammar in 1984. Attributed grammars were developed from the viewpoint of combining syntactic and statistical pattern recognition. In the meantime, the contextual information was also introduced into statistical pattern recognition. The unification of both syntactic and statistical approaches was always in his thoughts. Inference procedures of context-free programmed grammars, multi-dimensional grammars, transition network grammars, and stochastic tree grammars were developed one after another in the late 1970's through early 1980's. It is probably appropriate to say that all these constitute what we may call **Fu's theory of syntactic pattern recognition**. His treatise, "Syntactic Pattern Recognition and Applications", published in 1982, made this subject material more easily understandable to researchers and practitioners in various disciplines.

King-Sun and his colleagues also made important contributions to pattern recognition applications. His work on pattern classification of remotely sensed agriculture data (1969) and earth resources (1976) is considered classic in the field. During the mid 1970's through the early 1980's, his biomedical pattern recognition research extended to chest radiographic image analysis, automatic recognition of irradiated chromosomes, nucleated blood cell classification, and Pap smear and cervical cell image analysis and classification. The Moayer-Fu paper on fingerprint pattern recognition based on the syntactic approach received the 1976 outstanding paper award of the IEEE Transactions on Computers. His work on seismic signal discrimination and bright spots detection appeared in 1982 and 1985. His research on industrial automatic inspection and computer vision included IC chip inspection (1980), metal surface inspection (1984), and inspection of industrial assemblies (1985). An expert system was developed by his group for the assessment of structure damages caused by earthquakes (1983).

Since the late 1970's he envisioned the importance of integrated and special computer architectures and parallel algorithms for pattern recognition, image processing, and database management. This led to his works in 1980's on parallel parsing of tree languages, query languages for image database systems, and VLSI implementation of parallel parsing algorithm and hierarchical scene matching. In the meantime, his research on three-dimensional object representation and shape description, orientation estimation, overlapping workpiece identification, knowledge organization, and robotic vision for path planning laid the foundation for the establishment of

the Engineering Research Center on Intelligent Manufacturing Systems by Purdue University and the National Science Foundation in 1985. As mentioned earlier, King-Sun was the chief architect and the first director of the research center.

He wrote six books, edited or co-edited eighteen books, authored or co-authored forty-four book chapters, and one hundred sixty-two serial journal papers. In addition, he authored and co-authored two-hundred forty-eight conference papers. Seventy-two Ph.D. dissertations were completed under his supervision.

His activities in professional societies started in 1965–67 as the chairman of the Institute of Electrical and Electronic Engineers (IEEE) Discrete Systems Committee and the chairman of the Fifth Symposium on Discrete Adaptive Processes. Under his leadership he organized and served as the first chairman (1967–69) of the IEEE Automatic Control Group's Learning and Adaptive Systems and Pattern Recognition Technical Committee. He was on the official American delegation to the International Conference on Artificial Intelligence, Moscow, USSR, in 1967, and an official American delegate to the 1969 International Federation of Automatic Control (IFAC) International Congress held in Warsaw, Poland. He served on the administrative committee of the IEEE Automatic Control Group (1969–71) and later of the IEEE Control System Society (1974–76), was the chairman of the 1969 IEEE International Convention, a director (for IEEE) of the American Automatic Control Council in 1972, and the general chairman of the 1977 IEEE Conference on Decision and Control. He took part in the IEEE Systems, Man, and Cybernetics Society activities, beginning in 1969 when he served as the chairman of the Adaptive Systems Technical Committee of its predecessor, the IEEE Systems Science and Cybernetics Group, and was on the administrative committee of the Group (1970–72). He became the Cybernetics Technical Committee chairman (1972–76) and then the Society's Vice President for Technical Committees (1978–79). He was an associate editor of IEEE Transactions on Systems, Man, and Cybernetics (1969–1985).

In order to provide an international forum to promote advances in pattern recognition, he and the contemporary leaders in the field organized the first International Conference on Pattern Recognition in Washington, DC, in 1973, for which he served as chairman. The biannual conferences evolved into the formation of the International Association for Pattern Recognition (IAPR) by 1976. He was elected to be its president for 1976–78, a member of its executive committee (1976–80), chairman of its long range planning committee (1979–81), and a member of its governing board (1976–85). (In memory of his distinctive contributions, the IAPR has established since 1986 the "K. S. Fu Award" to be given to a distinguished contributor in the field once every two years.) In the meantime, he reorganized the Pattern Recognition Committee into the Machine Intelligence and Pattern Analysis Technical Committee (later renamed as the Pattern Analysis and Machine Intelligence Technical Committee) of the IEEE Computer Society and was its first chairman (1974–77). He was an associate editor of IEEE Transactions on Computers during 1977–78. His initiative led to the founding of the IEEE Transactions on Pattern

Analysis and Machine Intelligence, and he served as its first editor-in-chief (1978–81) as well as a member of the editorial committee (1981–85).

In addition, he served on editorial boards (editor, associate editor, and advisory board) of many other scientific journals. These include *Pattern Recognition* (associate editor, 1971–85); *International Journal on Information Sciences* (associate editor, 1970–82; editor 1982–85); *Journal of Cybernetics of the American Society of Cybernetics* (editorial board, 1970–85); *International Journal on Computer and Information Sciences* (advisory editor, 1971–85); *Journal of Information Processing* (editorial advisory committee, 1978–81); *Journal of Analytical and Quantitative Cytology* (editor, 1978–85); *International Journal of Fuzzy Sets and Systems* (advisory editor, 1979–1985); *International Journal of Cybernetics and Systems* (advisory board, 1980–85); *Computer Vision, Graphics and Image Processing* (associate editor, 1981–85); *Pattern Recognition Letters* (advisory editor, 1982–85); *IEEE Transactions on Geoscience and Remote Sensing* (associate editor, 1984–85); *IEEE Computer* (editorial board, 1983–85); and *Journal of Parallel and Distributed Computing* (editorial board, 1984–85).

He chaired and co-chaired the Engineering Foundation Conference on Pattern Information Processing in 1972, on Algorithms for Image Processing in 1976, and on Algorithms for Image and Scene Analysis in 1978. He was Program Chairman of the 1975 IEEE–ACM Conference on Computer Graphics, Pattern Recognition and Data Structure, of the 1978 IEEE Computer Society Conference on Pattern Recognition and Image Processing, and of the 1979 IEEE Computer Society COMPSAC Conference. He chaired the 1980 IEEE Picture Data Description and Management Workshop, and initiated and chaired the IEEE Computer Society Workshop on Computer Architecture for Pattern Analysis and Image Database Management in 1981 and 1983. He was the general chairman of the 1984 IEEE Workshop on Language for Automation; Honorary Chairman of the 1984 IEEE Workshop on Visual Languages at Hiroshima, Japan; and general chairman of the 1985 IEEE International Conference on Robotics and Automation. His leadership was well recognized for organizing many international joint seminars and workshops. He served as the coordinator of the NSF supported U.S.–Japan Seminar on Learning Processes in Control Systems at Nagoya, Japan, in 1970 and the Second U.S.–Japan Seminar on Learning Control and Intelligent Control at Gainesville, Florida, in 1973; as the vice-coordinator of the U.S.–Japan Seminar on Fuzzy Sets and Their Applications at Berkeley, California, in 1974; as a co-director of the NATO Advanced Study Institute on Pattern Recognition and Applications in 1975; as the co-chairman of the Dahlem Konferenzen on Biomedical Pattern Recognition and Image Processing at Berlin, West Germany, in 1979; and the coordinator of the NSF sponsored U.S.–France Seminar on the Applications of Pattern Recognition and Machine Intelligence to Automatic Testing at Alexandria, Virginia, in 1983. As a guest editor, he helped put together the special issue on “Feature Extractions and Selection in Pattern Recognition” of *IEEE Transactions on Computers*, September 1971; the special issue on “Syntactic Pattern Recognition” of *Pattern Recognition*, Part One,

November 1971, and Part Two, January 1972; special issue on "Pattern Recognition" of IEEE Computer, May 1976; and on "Robotics and Automation" of IEEE Computer, December 1982.

He was on the IEEE Computer Society Governing Board (1978–81), and served as the Society's Vice President for Publications and a member of the Executive Committee (1982–83) and Fellow Committee (1972–76, 1984–85). He served as the president of the Chinese Language Computer Society (1983–85). He was the Vice President (1984–85) and President-elect of the then newly formed IEEE Robotics and Automation Council. He was on the IEEE Fellow Committee (1977–79), IEEE TAB Awards and Recognition Committee (1979–78), American Federation of Information Processing Societies (AFIPS) Harry Goode Memorial Award Committee chairman (1982–85), American Society of Engineering Education (ASEE) Award Committee (1983–85), and IEEE Award Board, Education Medal Committee (1983–85).

King-Sun was literally showered with honor in recognition of his monumental research contributions and contributions to the profession. He was elected a Fellow of the Institute of Electrical and Electronic Engineers in 1971. He was elected a member of the National Academy of Engineering in 1976 and a member of the Academia Sinica in 1978. He served on the National Science Foundation's Advanced Automation Panel in 1973, Automation Research Council for 1972–78, and Committee on Cytology Automation of the National Institutes of Health, 1978–81. Among the many awards which he received are the Herbert N. McCoy Award in 1976 for Contributions to Science; the American Society of Engineering Education Senior Research Award in 1981 for outstanding loyalty and contributions as a pioneer in the contemporary engineering disciplines of pattern recognition, image processing and machine intelligence; IEEE Education Medal in 1982 for contributions to engineering education through inspired teaching and research in computer engineering, system theory and pattern recognition; American Federation of Information Processing Societies Harry Goode Memorial Award in 1982 in recognition of his contributions in pattern recognition and its applications and his leadership in education in information processing; Chinese Institute of Engineers — USA (CIE-USA) Achievement Award in 1983 for leadership in engineering education and contribution to pattern recognition; and the IEEE Centennial Medal in 1984.

King-Sun helped Taiwan, China, with his scientific advice in various ways. Over a period of fifteen years (1970–1985), he gave invited lectures there almost every year. He was the Program Chairman of the Academia Sinica International Computer Symposium at Taipei in 1978. He helped found the Institute of Information Science, Academia Sinica and was instrumental in establishing the Microelectronics and Information Science and Technology Research Center at the National Chiao Tung University, Taiwan, in 1984. He nurtured a number of young scholars who have become the principal researchers and engineers for the vital development of computer engineering and information science in Taiwan. Likewise he educated a number of scholars from mainland China during 1979 through 1985. He was invited

to give lectures to the Institute of Automation, Chinese Academy of Sciences in 1979, and was honored as a Distinguished Visiting Professor of Beijing University, an Honorary Professor of Tsinghua University, Beijing, and an Honorary Professor of Fudan University, Shanghai.

King-Sun took great pride in his two sons, Francis and Thomas, and one daughter, June. When they were young he always spent his leisure time playing ball or other sports with them. Together with Mrs. Fu, he provided their children with the best education in the home and at school. They are all grown up now: Francis is a computer engineer; Thomas, an oceanographer; and June, a biochemist. They have their own accomplishments in their respective professions.

In spite of his overwhelming achievements, King-Sun was a modest man with great sensitivity. Considerate and generous to his friends and students, he exemplified the notion of greatness both professionally and in his personal relationships with others. Standing alongside his outstanding contributions to the scientific world, King-Sun's great wisdom and human warmth will always be remembered.

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January 1997

Addendum to "A Bibliography of Published Works of the Late Professor King-Sun Fu," *IEEE Trans. Pattern Analysis and Machine Intelligence*, Vol. PAMI-8, No. 3, pp. 295–300, May 1986.

At the time of compiling the bibliography, eight items were missed (seven of which appeared later in 1986 and 1987). To make his bibliography complete, these are listed below.

Books:

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CONTENTS

Preface to the Second Edition	v
Preface	vii
Foreword	ix
A Memorial to the Late Professor King-Sun Fu	xiii
Contents	xxi
PART 1. BASIC METHODS IN PATTERN RECOGNITION	
1.1 Cluster Analysis and Related Issues <i>Richard C. Dubes</i>	3
1.2 Statistical Pattern Recognition <i>Keinosuke Fukunaga</i>	33
1.3 Syntactic Pattern Recognition <i>Kou-Yuan Huang</i>	61
1.4 Neural Net Computing for Pattern Recognition <i>Yoh-Han Pao</i>	105
1.5 On Multiresolution Wavelet Analysis using Gaussian Markov Random Field Models <i>C. H. Chen and G. G. Lee</i>	143
1.6 A Formal Parallel Model for Three-Dimensional Object Pattern Representation <i>P. S. P. Wang</i>	183
PART 2. BASIC METHODS IN COMPUTER VISION	
2.1 Texture Analysis <i>Mihran Tuceryan and Anil K. Jain</i>	207
2.2 Model-Based Texture Segmentation and Classification <i>R. Chellappa, R. L. Kashyap and B. S. Manjunath</i>	249
2.3 Color in Computer Vision: Recent Progress <i>Glenn Healey and Quang-Tuan Luong</i>	283
2.4 Projective Geometry and Computer Vision <i>Roger Mohr</i>	313

2.5	3-D Motion Analysis from Image Sequences using Point Correspondences	339
	<i>John. J. Weng and Thomas S. Huang</i>	
2.6	Signal-to-Symbol Mapping for Laser Rangefinders	387
	<i>Kenong Wu and Martin D. Levine</i>	
2.7	3-D Vision of Dynamic Objects	425
	<i>S.-Y. Lu and Chandra Kambhamettu</i>	

PART 3. RECOGNITION APPLICATIONS

3.1	Pattern Recognition in Nondestructive Evaluation of Materials	455
	<i>C. H. Chen</i>	
3.2	Discriminative Training — Recent Progress in Speech Recognition	473
	<i>Shigeru Katagiri and Erik Mcdermott</i>	
3.3	Statistical and Neural Network Pattern Recognition Methods for Remote Sensing Applications	507
	<i>Jón Atli Benediktsson</i>	
3.4	Multi-Sensory Opto-Electronic Feature Extraction Neural Associative Retriever	535
	<i>H.-K. Liu, Y.-H. Jin, Neville I. Marzwell and Shaomin Zhou</i>	
3.5	Classification of Human Chromosomes — A Study of Correlated Behavior in Majority Vote	567
	<i>Louisa Lam and Ching Y. Suen</i>	
3.6	Document Analysis and Recognition by Computers	579
	<i>Yuan Y. Tang, M. Cheriet, Jiming Liu, J. N. Said and Ching Y. Suen</i>	
3.7	Pattern Recognition and Visualization of Sparsely Sampled Biomedical Signals	613
	<i>Ching-Chung Li, T. P. Wang and A. H. Vagnucci, M.D.</i>	
3.8	Pattern Recognition and Computer Vision for Geographic Data Analysis	625
	<i>F. Cavayas and Y. Baudouin</i>	
3.9	Face Recognition Technology	667
	<i>Martin Lades</i>	

PART 4. INSPECTION AND ROBOTIC APPLICATIONS

4.1	Computer Vision in Food Handling and Sorting	687
	<i>Hördur Arnarson and Magnús Ásmundsson</i>	

4.2	Approaches to Texture-Based Classification, Segmentation and Surface Inspection	711
	<i>Matti Pietikäinen, Timo Ojala and Olli Silven</i>	
4.3	Context Related Issues in Image Understanding	737
	<i>L. F. Pau</i>	
4.4	Position Estimation Techniques for An Autonomous Mobile Robot—A Review	765
	<i>Raj Talluri and J. K. Aggarwal</i>	
4.5	Computer Vision in Postal Automation	797
	<i>G. Garibotto and C. Scagliola</i>	
4.6	Vision-Based Automatic Road Vehicle Guidance	817
	<i>Dieter Koller, Quang-Tuan Luong, Joseph Weber and Jitendra Malik</i>	
PART 5. ARCHITECTURE AND TECHNOLOGY		
5.1	Vision Engineering: Designing Computer Vision Systems	857
	<i>Rama Chellappa and Azriel Rosenfeld</i>	
5.2	Optical Pattern Recognition for Computer Vision	869
	<i>David Casasent</i>	
5.3	Infra-Red Thermography: Techniques and Applications	891
	<i>M. J. Varga and P. G. Ducksbury</i>	
5.4	Viewer-Centered Representations in Object Recognition: A Computational Approach	925
	<i>Ronen Basri</i>	
5.5	Video Content Analysis and Retrieval	945
	<i>Hongjiang Zhang</i>	
5.6	VLSI Architectures for Moments and Their Applications to Pattern Recognition	979
	<i>Heng-da Cheng, Chen-Yuan Wu and Jiguang Li</i>	
	Index	1003