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13. ABSTRACT (*Maximum 200 words*)

We have developed a method for the analysis and interpretation of gray images using a new definition of connected components that is dependent on two parameters. We considered the topological properties of gray images on an arbitrary grid. We presented an algorithm for the matching of space curves. We developed a method of object recognition by computing the invariants of conics. We developed an intelligent product selection method, using fuzzy logic. Finally we investigated a hierarchical prioritization scheme for a family of belief structures where we may dynamically adjust the priorities.

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- Total duration of project: November 1, 1993 — May 31, 1997.

1 Accomplishments

1.1 Gray Image Understanding

Segmentation is a fundamental problem in low–level computer vision. We introduced a new definition of connected components for a gray image which depends on two parameters denoted by ϵ and δ which are arbitrary nonnegative integers. As the proposed definition involves both gray values of pixels and the variations of the gray values, we may conveniently adjust the corresponding parameters ϵ and δ for different problems or different kinds of images to partition an image, so that each (ϵ, δ)-component is a desired object for a certain problem. We have discussed some properties which are derived from our new definition. We have given an algorithm to partition a gray image such that each member of the partition is an (ϵ, δ)-component of the image. Since we do not make any assumption about the formation model of the image data, our algorithm can be applied to many different kinds of images, such as binary, light intensity, X-ray, range and magnetic resonance images, *etc.* Implementation has been given on a large class of images. A practical advantage of the concept of (ϵ, δ)-components of an image is that we can extract the objects we are interested in for a certain problem from the background. So we are able to concentrate on the object areas rather than the whole image. Another benefit is that we can study an entire image through the inter–relationships of the (ϵ, δ)-components, or even further, of the high–lands or low–lands, rather than that of the pixels of the image. Our theory provides a possible method of transition from low level computer vision to an intermediate level vision. Since the latter describes the inter–relationships of the objects in an image, it helps us to understand the image macroscopically in an easier manner than through the study of the relationships of the pixels of the image.

For a given image we can easily find various types of properties that are based on only the pixels. We called this a *low level understanding.* At the content understanding level, we concentrated on the properties of some groups of pixels. The pixels in the same group have some common properties, such as having the same distribution of the gray values, possessing a certain shape, etc. In practical problems, it is often not enough to understand an image only at the pixel level. We may need to understand the content of an image. This raised another question: how to group the pixels in the image such that each group represents an object under consideration? There are many ways to group the pixels in an image, such as thresholding, multi-thresholding etc. The grouped pixels may represent the objects aptly in some ways, while not good in other ways. The pixel-grouping problem is what the component understanding level needs to resolve. At this level, we understand the structure of an image in terms of its components rather than only by its pixels. So, we regarded this as an intermediate level of image understanding.

Using the various component histograms, we proposed a method to understand an image at the intermediate level. Using the pre-knowledge about a certain kind of objects, we can find the appropriate values of ϵ and δ such that the objects in an image can be represented by its corresponding components reasonably well. Object extraction and segmentation can then be done by locating these components. Thus, using the (ϵ, δ)-components as a tool, we can understand an image beginning from the intermediate level to the higher level. We do not make any assumptions about the model of the image data, the only things that we take into account in our method to find the components are the gray values of the pixels as well as their variations. Therefore, our method to understand an image through its components can be applied to many types of images.

To understand an image in a macro-view, we concentrated on the statistical properties of its components. The most obvious statistic is the number of the components. The gray-value histogram upon pixels is an important tool to analyze the statistical property of the pixels in an image. We considered various histograms upon the components, instead of the pixels, to analyze the distributions of the different properties of the components in an image. We refer to this kind of histogram as a *component histogram.* For any given values of the parameters and given strategies to find a seed point, the components of an image are determined uniquely. If the shapes of the components are limited only to those of simple geometrical shapes (such as a rectangle, a disk, etc.), we may create a component histogram for the shape also. Here, the values along the horizontal axis may be a code of the different shape names. From a component histogram of the shape, we can easily find the number of rectangles, triangles, etc., in the image. (This would be specially helpful to analyze, e.g., engineering drawings.) By analyzing these component histograms, we can understand an image not only at the pixel-level but also at a higher component-level.

We have also developed a new feature-based method for the correspondence problem of stereo images. The features we choose for matching are the boundaries of certain parameter-dependent connected components of gray images that were introduced by us in a previous work. Under certain assumptions, there is a one-to-one relationship between the sets of the points on the boundaries of the components of the two stereo images. This correspondence can be identified through the standard epipolar geometry. Once we have the corresponding boundaries in stereo images, we may directly match the connected components determined by the boundaries. If we choose the values of the parameters appropriately, such connected components may represent meaningful objects in an application. Thus, we may able to recover the depth information of an object immediately, rather than through every points on the surface of the object which is usually impossible or time-consuming or unnecessary for some applications. On the other hand, if we do need the details of the surface of an object, a hierarchy of the connected components provides us a coarse-to-fine matching method to recover the surface corresponding to a connected component. The depth information of a 3-D object is essential in many applications such as radar systems, robotics, laser ranging, remote sensing, etc. However, this information is not contained in any single image. Stereo vision allows us to recover this information using a pair of stereo images that are projections of the same 3-D object(s) from different points of view. For a pair of stereo images, if we could determine which object in one image corresponds to a given object in the other image, then there is a standard theory to compute the depth of this object. If we take each point of an image as an object, then the surface formed by these points may be uniquely reconstructed once we find all the corresponding points. We have proposed a new feature-based method for the correspondence problem. The features we used for matching, are the boundaries of the components of an image. Under certain constraints, there is a one-to-one relationship between the sets of the boundary points of a component on the conjugate epipolar lines. Using this relationship, we may find the boundary on the other image corresponding to the given boundary of an (ϵ, δ)-component on an image. Consequently, we may obtain, uniquely, the corresponding components represented by the corresponding boundaries. Further work on this application have been proposed in a DEPSCOR grant application to the AFOSR that is currently under review.

1.2 Well-Composed sets and Jordan Curves

We have considered the topological property of connectivity on a digitized plane on an arbitrary grid. We have proved a digital version of the Jordan curve theorem and its converse for an arbitrary grid system. We have extended the concept of the well-composed set which was introduced by Latecki, Eckhardt and Rosenfeld (1995), from the quadratic grid system to an arbitrary grid system. Combining the concept of the well-composed set with that of the parameter-dependent connected component introduced by us earlier, we allowed a connected component of a well-composed set to contain pixels which have different gray values. This combination provided us with more flexibility for studying the connectedness property because in real-world image, objects usually have different gray values.

Since a digital image is usually represented by a square area on a quadratic grid system, results on digital connectivity have been mainly obtained for this specific grid system by various researchers and these may not be always applicable to other grid systems. We proposed some new definitions of digital connectivity that is independent of the grid system. Then, we prove the corresponding digital version of the Jordan curve theorem and its converse. We also extend from the quadratic grid system to an arbitrary grid system the concept of the *well-composed set* that was introduced by Latecki, Eckhardt and Rosenfeld (1995). Since an object in an image usually has multi-gray-values, we often need to know the relationship of connectedness among the objects. So, it may be more useful to study connectedness among the components that have different gray values than to study it among those components that have only the same gray value. We combined the concept of the well-composed set and a parameter-dependent connected component. We found that each connected component of a well-composed set may contain the pixels which have different gray values. In our previous work, we have shown that for some appropriate parameter values, a parameter-dependent component may represent an object of an image reasonably well. So, the connectivity of the connected components describes the connectivity of the corresponding objects of the image.

In order to get a digital version of some results on connectivity for the continuous plane, we need to use two types of connectedness for different subsets of the pixels in a digital image. Consequently, we need to choose which connectedness should be used for which subsets (e.g., the foreground or the background) of the image, and different choices usually generate different results. In practice, such a choice is not always obvious. Latecki, Eckhardt and Rosenfeld (1995) introduced the interesting concept of *well-composed sets* for binary images on the quadratic grid system which allows us to avoid the connectivity paradoxes while having only one connectedness relation for the entire digital image. Latecki (1995), extended the concept of well-composed sets to multicolor images. We extended further the concept of well-composed sets in two directions. First, we extended the well-composed sets to an arbitrary grid system. Second, we allowed the members of each set of pixels in an image to have different gray values. The pixels in each set used in Latecki, Eckhardt and Rosenfeld (1995) and Latecki (1995) to consider connectivity have been limited to have the same gray value. In practical situations, the pixels in an object usually have different gray values. To study connectedness among the objects of an image, we relaxed this condition to allow the pixels in a set to have different gray values. We also considered how we can use the concept of a *parameter-dependent connected components* from our work last year to extend a well-composed set to have different gray values.

1.3 Matching of 3-D Polygonal Arcs

Matching of arcs is a basic problem in computer vision. It is used in many applications, e.g., industrial parts inspection, character recognition, analysis of engineering drawings, etc. The problem of finding an approximate match between short arcs and pieces of a long arc is known as the *segment matching problem.* There have been several approaches to this problem. These can be classified as global or local in nature. In the global approaches, a set of global features are obtained for each arc and we match these features for the two arcs. The 3-D generalization of the matching of polygonal arcs is of considerable interest in computer vision: the problem has applications in industrial parts inspection, motion estimation, structure determination of macromolecules from electron density maps, and in many other 3-D vision problems. Also, a polygonal approximation provides a data compression of images and several contour segmentation techniques have been proposed which have applications in the design of the vision system of a mobile robot. We have done further work on the problem continuing our efforts of last year.

An algorithm was presented to match 2-D polygonal arcs of arbitrary shapes by Rosenfeld al. (1991) generalizing their previous algorithm to match 2-D rectilinear arcs. We extended their algorithm for the case of 3-D polygonal arcs. We defined a distance measure between 3-D polygonal arcs and use this to develop a matching algorithm for 3-D arcs. The 3-D generalization of the matching of polygonal arcs is of considerable interest in computer vision: the problem has applications in industrial parts inspection, motion estimation, structure determination of macromolecules from electron density maps, and in many other 3-D vision problems. Also, a polygonal approximation provides a data compression of images and several contour segmentation techniques have been proposed which have applications in the design of the vision system of a mobile robot.

There are several novel features in our approach that distinguishes it from previous works on matching of 3-D curves. Unlike the previous works, we use here unit quaternions to denote 3-D rotations that, as is well known, has the advantage (over other representations for rotations) in giving a closed form solution. Further, we proved a new result interpreting the extreme values of the distance measure for two 3-D polygonal arcs of equal lengths as the eigenvalues of a certain (well defined) 4×4 positive semidefinite matrix; the minimum value of the distance measure corresponding to the minimum eigenvalue of this matrix. It follows that the matching problem of 3-D curves can now be reduced to the purely algebraic problem of studying the eigenvalues of a certain matrix. We applied the same approach to matching 2-D polygonal arcs. We showed that a subgroup of the unit quaternions can be used to denote 2-D rotations. Using this subgroup of the unit quaternions, we proved that the minimum value of the the distance measure between two 2-D polygonal arcs is the smallest eigenvalue of the 2×2 submatrix located in the lower right quadrant of the 4×4 matrix used in 3-D matching. It follows that the matching problem of 2-D curves can now be reduced studying the eigenvalues of matrix. We then could apply standard methods of numerical linear algebra to estimate the eigenvalues and hence the matchings (up to any desired degree of accuracy). Our algorithm is practical to implement and we have carried out extensive implementations.

1.4 Applications of Legendre Transformation to Computer Vision

The *Legendre transformation* is a well known concept in classical theoretical physics. Recently, I. Weiss of the Center for Automation Research, University of Maryland, applied it to study problems of invariance in computer vision; his results were presented in the 1994 and 1995 ARPA Image Understanding Workshops. Most authors treat the Legendre transformation (LT) purely analytically . Only the famous Russian theoretical physicist Arnold (1978) has treated the LT from a geometric point of view; also a very general version of the LT for a hypersurface and the relationship with symplectic invariants are discussed in a monograph by Hofer and Zehnder (1994). We obtained some new geometric properties of the LT that are of potential interest in image understanding. We showed that under the LT the cross ratio, and the connectedness property remain invariant. Also, we show that the LT maps a conic into a conic. As an application we developed an algorithm to detect corners in images. We also discussed the relationship of the LT with the classical Hough transform.

1.5 Parallel Architecture for Component Labeling

Connected component labeling is a basic operation in machine vision. The purpose of labeling is to treat the individual connected components of a digitized image as separate objects and obtain a multivalued picture in which the points corresponding to each component have a unique non-zero label. Two algorithms for connected component labeling for binary images are given in Rosenfeld and Kak (1982) – a sequential algorithm, and a parallel algorithm on a fixed connection mesh connected computer. Both these have run times $O(n^2)$ for images of size $n \times n$. Our aim was to present two parallel algorithms for connected component labeling for binary images on a reconfigurable mesh architecture.

Multi-dimensional meshes are among the most widely used interconnection networks in existing parallel machines. The two dimensional mesh with reconfigurable buses consists of an $n \times n$ array of processors connected to a grid shaped reconfigurable broadcast bus. Along each dimension, a processor has two local ports connecting it to the bus. The entire mesh operates in synchronous MIMD (Multiple Instruction Multiple Data) mode with a processor executing an instruction of its own local program at every tick of a global clock. In a scenario when more than one processors connected to a common bus subsystem broadcast a message at the same time, the contents of the message are unpredictable. When such a multiple broadcast takes place, there is a very vital information which is still gathered by all the connected processors.

1.6 Object Recognition Using Conics

Many natural and human-made shapes can be approximated by conics. Conics are widely recognized in the study of machine vision as the most fundamental image features next to lines. Many natural and man-made objects have circular shapes, and in addition, many other curves can be approximated by conics. Arbitrary planar shapes can be represented by a set of coplanar conics. There has been considerable work done in recognizing pairs of coplanar conics using invariants. In this project we proposed to extend the use of invariants to families of coplanar conics of any size. The proposed invariants can discriminate between two non-projectively related families of coplanar conics in which the previously used invariants give the same value. Invariants are properties of geometric configurations which remain unchanged under an appropriate class of transformations. Mutual invariants are properties of a set of objects that remain unchanged under a class of transformations.

The number of independent absolute invariants of a family of conics depends on the number of conics in the family. The number of independent absolute invariants may be found by using dimensional analysis as done in Quan. For two conics there are two independent absolute invariants. For three conics there are seven independent absolute invariants. Each additional conic will add five more independent absolute invariants. The absolute invariants are not unique. Depending on the application, we may not need to use all of the independent absolute invariants, but only a subset of the independent absolute invariants. When using a subset, we make sure that the sum in condition 2 for a conic is not zero for all of the invariants in the subset; if it is zero then the invariants in that subset will not depend on that conic. In fact, the subset is a set of independent absolute invariants for the family of $n-1$ conics which is the original family less that conic.

By calculating the Θ's of a family of conics as an intermediate step to calculating the absolute invariants, we have the values needed to calculate the absolute invariants for any subset of the family of conics. A set of these independent absolute invariants and the Segre characteristic was used as the invariant descriptors of a family of coplanar conics.

The use of invariants for two coplanar conics have been proposed by a number of authors but there has not been any work so far to develop invariants of three or more conics. So, in order to compare our proposed invariants we needed to compare them with the previous works for two coplanar conics. The comparison was made against invariants presented by Forsyth, Quan, and Maybank. By combining our results we saw that using just it was not enough to show that two pairs of coplanar conics are equivalent. Thus, additional information of the Segre characteristic is needed to show the two pairs of coplanar conics are equivalent. To demonstrate this, we considered two synthetically generated pairs of conics (not shown here due to limitations of space) and for these we noticed that just using the invariants proposed by the previous researchers are not enough to distinguish between them. It was seen without doubt that the use of the Segre characteristic discriminates between the two pairs.

The noise in an image may affect the coefficients of the conics that are found in the image. How the noise affects the coefficients of a conic is dependent on the method used to find and fit the conic. To isolate the effects of noise on the proposed invariants, we added simulated noise to ellipses and compared the invariants of the noisy ellipse and the original ellipse.

1.7 Intelligent Product Selection and Decision Making

Product selection is a complex decision making process problem and the type of uncertainty present is human uncertainty inherent in subjective judgments. We developed an application for selecting a particular database software package based on the attributes of online help files and written documentation. We considered the problem selecting a product when uncertainty is present. In the real world we make decisions everyday and the decision maker has to choose one among many alternatives and specify the optimal alternative. The uncertainty of subjective judgment is present when this happens. Also this is a difficult problem to solve when there is imperfect information. A system was proposed based on fuzzy logic and we applied it for the specific problem of product selection for database software packages.

1.8 Dempster-Shafer Theory and Hierarchical Prioritization

In many real-time applications, it is often necessary to make decisions based on a vast amount of evidence. Consequently, several belief structures are often involved in the processing of evidence. We investigated the properties of the conjunction of a family consisting of a number of belief structures. Later, we also investigated the aggregation of several families of belief structures. Our investigations may give further understanding of the behavior and usefulness of Dempster's rule of combination. Our proposed scheme of nonhierarchical prioritization is more flexible than the standard hierarchical prioritization as we may dynamically adjust the priorities according to our needs at any stage of investigation of evidence.

Our first objective was to investigate the behavior of certain evidence-theoretic functions under the conjunction of a family of belief structures. We compared the function value of the conjunction on the various focal elements with the corresponding values for the belief structures in the given family. To begin with, we considered the case when there is no conflict and show that the ignorance is decreased when we compute the conjunction of a family of belief structures. Also, we obtained certain estimates of the products of the beliefs and plausibilities of a family of belief structures in terms of the belief and plausibility of the conjunction. Then, we considered the more general situation when the conflict in a given family of belief structures is nonzero. We showed that the "nonspecificity" of the conjunction is smaller (by a certain scale factor that is a function of the degree of conflict) than the nonspecificities of all the belief structures of the family.

Next, we considered a model of nonhierarchical aggregation that has potential applications in the management of uncertainty in knowledge-based systems. The traditional model considers prioritizing the belief structures hierarchically. Although there is a wide class of situations where such a model is applicable, yet there are also many situations where it may not be possible to use such a model. In our proposed model, there is no hierarchical order and any belief structure in the given family may be prioritized. We show that the conjunction of such a family of belief structures is such that the belief–plausibility interval for any focal element is contained within the corresponding belief-plausibility interval for each belief structure of the family. AIn other words, the ignorance of the conjunction is less than or equal to the ignorance of each of the belief structures – this result holds in all cases whether the conflict is zero or not, extending the result mentioned in the last paragraph for the zero conflict case. We proposed several types of inheritance networks – strong, weak, hybrid and multi-level – each of these networks allow a certain amount of flexibility in the choice of prioritization.

We examined the behavior of certain evidence-theoretic functions when the Dempster's rule of combination is applied to a family of belief structures. The models of inheritance network proposed in this work allow strong, weak and hybrid inheritances. We considered the extension of our results to the case of a class of several families of belief structures each defined on the same frame of discernment. Our investigations indicated that the Dempster's rule of combination is useful in reducing the ignorance regarding the belief structures.

2 Personnel Supported

- Staff
  1. Prabir Bhattacharya, PI.
  2. Yang Wang, graduate research assistant.
- Consultants
  1. Professor A. Rosenfeld, Honorary Consultant
  2. Professor R. Chellappa

3 Technical Publications

3.1 Journal Papers

1. P. Bhattacharya, "Estimation of Aspect Angles of Targets in Forward-Looking Infrared Images," *Optical Engineering*, vol. 33, no. 10, pp. 3334-3341 (1994).
2. P. Bhattacharya, "Parallel, Optical Image Processing by the Image-Logic Algebra," *Applied Optics*, vol. 33, no. 26, pp. 6142-6145, (1994).
3. P. Bhattacharya and Y.K. Yan, "Iterative Histogram Modification Of Gray Images," *IEEE Trans. on Systems, Man & Cybernetics*, vol. 25, no. 3, 521-523 (1995).
4. P. Bhattacharya, W. Zhu and K. Qian, "A New Shape Recognition Method Using Morphological Hit-Miss Transform And Algebraic Representation of Images." *Optical Engineering*, vol. 34, no. 6, pp. 1718-1725 (1995).
5. P. Bhattacharya and T. Wong, "Design of a Graphic Interface for a Part's Inner Feature Detection," *Computers in Industry*, vol. 27, pp. 251-257 (1995).
6. Y. Wang and P. Bhattacharya, "On Parameter-Dependent Connected Components of Gray Images," *Pattern Recognition*, vol. 29, no. 8, pp. 1359-1368 (1996).
7. P. Bhattacharya and D. Wild, "A New Edge Detector for Gray Volumetric Data," *Computers in Biology and Medicine*, vol. 26, no. 4, pp. 315-328 (1996).
8. P. Bhattacharya, "Connected Component Labeling for Binary Images on a Reconfigurable Mesh Architecture," *Journal of Systems Architecture*, vol. 42, no. 4, pp. 309-313 (1996).

9. D. Heisterkamp and P. Bhattacharya, "Matching of Three-Dimensional Polygonal Arcs," *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 19, no. 1, pp. 68-73, (1997).

10. D. Heisterkamp and P. Bhattacharya, "Invariants of Families of Coplanar Conics, and their Applications to Object Recognition," *Journal of Mathematical Imaging and Vision*, vol. 7, pp. 253-267, (1997).

11. Y. Wang and P. Bhattacharya, "Digital Connectivity and Extended Well-Composed Sets for Gray Images," *Computer Vision and Image Understanding*, accepted for publication. To appear in vol. 68, no. 1, October, 1997. 16 journal pages.

12. D. Heisterkamp and P. Bhattacharya, "Matching of 2-D Polygonal Arcs Using a Subgroup of the Unit Quaternions, *Computer Vision and Image Understanding*," accepted for publication.

13. D. Heisterkamp and P. Bhattacharya, "Geometric Properties of Legendre Transformations," *Computer Vision and Image Understanding*, tentatively accepted for publication, subject to revision.

14. Y. Wang and P. Bhattacharya, "Hierarchical Stereo Correspondence Using Features of Gray Connected Components," submitted.

15. L. L. Machacha and P. Bhattacharya, "Uncertainty Pertaining to Expert Judgment in Product Selection," submitted.

16. P. Bhattacharya, "On the Dempster-Shafer Evidence Theory and Nonhierarchical Prioritized Aggregation of Belief Structures," submitted.

17. Y. Wang and P. Bhattacharya, "An Algorithm to Find Parameter-Dependent Connected Components of Gray Images," submitted.

18. Y. Wang and P. Bhattacharya, "Connected Components, Segmentation and Image Understanding," submitted.

19. K. Qian, S. Cao and P. Bhattacharya, "A Ridge-Seeking Skeletonization Algorithm for Gray Images," submitted.

3.2 Refereed Conference Papers

20. Y. Wang and P. Bhattacharya, "A Theory of Parameter-dependent Connected Components of Gray Images", *Proc. IEEE International Conf. Image Processing*, Washington, D.C., Oct., 1995, pp. 69–72, vol. 3.

21. D. Heisterkamp and P. Bhattacharya, "Matching of 3-D Curves", *Proc. IEEE Internat. Conf. Robotics and Automation*, Minneapolis, April, 1996, pp. 3490–3495.

22. D. Heisterkamp and P. Bhattacharya, "Invariants of a Family of Coplanar Conics and Object Recognition," *Proc. 13th Internat. Conf. Pattern Recognition* (ICPR'96), Vienna, Austria, August, 1996, Computer Vision Track, pp. 677-681.

23. Y. Wang and P. Bhattacharya, "Parameter-Dependent Connected Components, Segmentation and Image Understanding," *Proc. IEEE Internat. Conf. Systems Man and Cybernetics*, Oct., 1996, vol. 1, pp. 444-449.

24. Y. Wang and P. Bhattacharya, "Gray Connected Components in Hierarchical Correspondence of Stereo Images," to appear in *Proc. IEEE Internat. Conf. Image Processing*, Santa Barbara, CA, 1997.

4 Interactions/Transitions

4.1 Participation/presentations at meetings, conferences, seminars, etc.

- **Memberships of program Committees of Conferences**

  1. 28th International Conference on Automotive Technology and Automation, Dedicated Conference on Robotics, Motion and Machine Vision, Stuttgart, Germany, 1995.
  2. 18th SPIE Conference on Applications of Digital Image Processing, San Diego, CA, 1995.
  3. 19th SPIE Conference on Applications of Digital Image Processing, Denver, CO, 1996.
  4. 29th International Conference on Automotive Technology and Automation, Dedicated Conference on Robotics, Motion and Machine Vision, Florence, Italy, 1997.
  5. 20th SPIE Conference on Applications of Digital Image Processing, San Diego, CA, 1997.
  6. 4th IEEE International Conference on Image Processing, Santa Barbara, CA, 1997.

- **Chairing sessions in conferences**

  1. 18th SPIE Conference Applications of Digital Image Processing, San Diego, CA, July, 1995. Chaired two sessions.
  2. 28th International Conference on Automotive Technology and Automation, Dedicated Conference on Robotics, Motion and Machine Vision, Stuttgart, Germany, 1995. Chaired two sessions.
  3. 19th SPIE Conference Applications of Digital Image Processing, Denver, CO, August, 1996. Chaired a session.
  4. 13th International Conference on Pattern Recognition (ICPR'96), Vienna, Austria, August, 1996. Chaired a session in the computer vision track.

- **Presentations in Conferences**

  1. Second IEEE International Conference on Image Processing (ICIP'95), Washington, DC.1995. (Dr. J. Sjogren of AFOSR/NM kindly attended the presentation).
  2. 18th SPIE Conference Applications of Digital Image Processing, San Diego, CA, 1995.
  3. IEEE International Conference on Robotics and Automation, Minneapolis, Minnesota, 1995.
  4. Invited presentation at the Workshop on Mathematics of Computer Vision, Geometry Center, University of Minnesota, Minneapolis, 1995.
  5. Invited presentation at the Bose Memorial Conference on Statistics and Combinatorics, Fort Collins, CO, 1995. Organizer: AFOSR.
  6. Invited presentation at the German National Cancer Research Institute, Heidelberg, Germany. Department of Radiology, 1995.
  7. 19th SPIE Conference on Applications of Image Processing, Denver, Colorado, 1996.
  8. 13th International Conference on Pattern Recognition (ICPR'96), Vienna, Austria, August, 1996.
  9. 34th Allerton Conference on Communications, Control and Computing, University of Illinois at Urbana-Champaign, 1996.
  10. IEEE International Conference Systems Man and Cybernetics, Beijing, China, 1996.
  11. SPIE Conference on Visual Communications, San Jose, CA, 1997.
  12. SPIE Internat. Sympos. Aerospace & Remote Sensing, 1997, Orlando, Florida.
  13. Invited presentation at the Indian Institute of Technology, Department of Computer Science and Engineering, New Delhi, 1997.
  14. 5th European Conf. Intelligent Techniques and Soft Computing, Aachen, Germany, September, 1997.
  15. Fifth IEEE International Conference on Image Processing, Santa Barbara, CA, 1997.

4.2 Interaction with Air Force Laboratories

1. The PI gave a presentation of his work at the Wright-Patterson Air Force Laboratory, Dayton, OH in 1995. He gave two talks on successive days and also held detailed discussions with some staff members including V. Velten and J. Leonard.

2. The PI had a discussion with researchers from the Air Force Laboratory, Rome, NY during the 19th SPIE Image Processing Conference held in Denver, Colorado in Aug 5–9, 1996 who are also working on stereo problem for tracking point targets. This group from the Rome Lab presented a paper on the topic in the session in the Conference that was chaired by the PI.

3. The PI was invited to participate in the Smart Sensors Workshop held in 1996 at the Air Force Laboratory at the Kirtland Air Force Base in Albuquerque, NM. He also gave a poster presentation at the workshop. During the workshop, he benefited greatly by interacting with the other participants including several Air Force staff.

4.3 Consultative and advisory functions to other laboratories

None.

4.4 Transitions

The results from our effort could be used in developing technology for automatic target recognition by providing hierarchical matching of stereo images, image segmentation and multi-dimensional signal processing. We have discussed part of our technical efforts with Mr. Vincent Velten of the WL/AARA, of the Wright-Patterson AFB, Dayton, Ohio.

5 New Discoveries, inventions, or patent disclosures

None.

6 Honors/Awards

1. National Lecturer of the Association of Computing Machinery (ACM) during 1996-99.

2. Distinguished Visitor of the IEEE Computer Society during 1996-99.

3. Award for highest involvement from the Nebraska chapter of the IEEE Computer Society, 1996.

4. Certificate for being an outstanding member from the Nebraska chapter of the IEEE Computer Society, 1996.

5. Editorial board member of the IEEE Computer Society Press during 1996-98.

6. Editorial board member of "Pattern Recognition" during 1994-present.

7. Elected the Chairman of the IEEE Computer Society, Nebraska Chapter for 1995-96, and re-elected for 1996-97.