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Final Report to the Army Research Office: Intelligent Decision Strategies and Some Applications

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FINAL REPORT

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5. **NAME OF INSTITUTION:** Purdue University

6. **AUTHOR OF REPORT AND PRINCIPAL INVESTIGATOR:**

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1. BRIEF SUMMARY OF RESEARCH CONTRIBUTIONS

We have made fundamental research contributions in the two areas (a) and (b) mentioned in the original research proposal for ARO.

(a) Model Based Decision Methods for Image Segmentation and Other Applications

(a1) Visual texture is an important aspect of images. Traditionally, all edges in an image were considered as "intensity" edges since they were defined in terms of the chiinge in the intensity across the edge pixel. However, we showed that even when there is no sharp change in the intensity across a pixel, still an edge is visible caused by the differing textures across the pixel and these edges were defined as texture edges. We have developed systematic methods of detecting both texture edges and intensity edges in real images. A two stage generate-and-confirm paradigm is developed for detecting the edges. The texture edges are detected by fitting a parametric random field model - the so-called nonsymmetric half plane (NSHP) model. The results are published in the journal paper [Eom, Kashyap, 1990].

The above method does not use any prior knowledge of the pattern. We can improve the sharpness of the segmentation boundaries by using prior knowledge of the patterns expressed in terms of a procedure or rules. Li [1990] has shown that there is a considerable improvement in the quality of segmentation by using these rules.

(a2) Shape from a Textured and Shaded Surface Image

To recover 3-D structure from a textured and shaded surface image, neither the shape-from-shading nor the shape-from-texture analysis is enough, because information of both radiance and texture coexist within the scene surface. A new 3-D texture model. is developed by considering the scene image as the superposition of a smooth shaded image and a random texture image. For the deterministic part of the model the modified reflectance map function with the normalization factor is applied and for the random part the orthographically projected long-correlation periodic model is developed to take care of the non-isotropic distribution function, because the long-correlation periodic model has the ability to represent the coarseness and the pattern of the surface at the same time. These two parts of the model are superposed in the frequency domain and the estimation and the synthesis is done based on the local patch analysis. For estimating the surface orientation parameters, a hybrid method which uses both the least square and the maximum likelihood estimates is applied directly to the given intensity function. By using these parameters, the synthesized image is obtained and used to reconstruct the original image. The contribution of this research will be in combining shape-from-shading and shape-from-texture techniques to extract 3-D structure and texture pattern features directly from a single image which contains both shade and texture in it without requiring any pre-processing. The details are in the journal paper [Choe and Kashyap, 1991], [Choe, 1990].

(b) Robust Combination of Uncertain Evidence from Several Different Sources and Their Application

(b1) We consider the development of mathematical procedures for combining different pieces of evidence and their propagation in a lattice structured net. The application of Shafer's belief function to deal with uncertainty in expert systems has attracted much attention in artificial intelligence research. Due to the incomplete and inexact nature of information, uncertainties in an inference network can be properly represented by intervals in [0,1] and modeled by Shafer's belief functions. Reasoning with uncertainty in an inference network consists of the aggregation of uncertain information from various sources. Three types of belief aggregation operation can be identified: belief conjunction, belief combination, and belief propagation. Previous belief function approaches have focused on using Dempster's rule to deal with the belief combination problem without mentioning how to formally deal with belief propagation problem. Furthermore, as we shall illustrate, Dempster's rule lacks robustness when combining highly conflicting evidence.

The cause of the nonrobustness is discussed and an alternative belief combination procedure is proposed to remedy the deficiency. Although the proposed belief propagation procedure yields results that are dependent upon the interpretations of the rule, the belief propagation procedure is shown to be an interpolation between total ignorance [0,1] and the uncertainty associated with the rule regardless of the interpretations. When the rule interpretation yields associative belief propagation procedure, corresponding chaining syllogism for belief propagation procedure can be derived. Finally, the proposed inference procedure:; are applied to lattice-structured inference network. The work discussed in this paper is intended to provide a unified framework to belief combination and belief propagation. The results are contained in the journal paper [Hau and Kashyap, 1990].

(b2) Axiomatic Approach to Evidence Combination

The thesis by Chang presents a new mathematical procedure for combining different pieces of evidence which are represented in the interval form to reflect our knowledge about the truth of a hypothesis. Evidences may be correlated to each other (dependent evidences) or conflicting in supports (conflicting evidences). First, assuming independent evidences, we proposed a methodology to construct combination rules which obey a set of essential properties. The method is based on a geometric model. We compare results obtained from Dempster's, intervals Bayes and the proposed combination rules with both conflicting and non-conflicting data and show that the values generated by proposed combining rules are in tune with our intuition in both cases. Secondly, in the case evidences are known to be dependent, we analyze the dependency problem in terms of the modified Bayesian approach. We also consider extensions of the rules derived earlier to handle dependency in evidences. The performance of proposed rules are shown by several different examples. The results show that the proposed rules reasonably make decision under dependent evidences. The details are in the Ph.D. thesis by Chang

and the paper [Kashyap and Chang, 1990].

(b3) Applications of the Theory of Evidence Combination

Geometrical reasoning for recognition of three dimensional object features, a method for extracting shape features from the boundary representation of a solid polyhedral object, is presented. In this approach the part is represented as a global graph, from which the labelled graphs called cavity graphs corresponding to the depressions in the boundary of the object are constructed. Both edges and vertices of cavity graphs are labelled. The cavity graphs are used to generate a set of hypotheses about the primitive features interacting in the depression. Rule-based experts using a cooperative reasoning scheme select the correct hypotheses.

Emphasis is placed on recognizing interacting features not extracted by previous methods. Toward this end, we have developed a series of measures to correctly extract primitives when intersecting faces of a primitive become separated, or some faces of a primitive split into disconnected pieces as a result of its interaction with other primitives. Hence, the method tolerates the cases in which the cavity graph representation of the primitive in interaction is different from the isolated representation. Experimental results for a number of example, which are not correctly analyzed by previously proposed systems, are presented throughout the paper and implementation details are discussed. The details are in the journal paper [Marefat and Kashyap, 1990].

We have used the evidence combination methodology for achieving information routing and sensor fusion [Iyengar, et al., 1992; Jayasimha, et al., 1991; Prasad, et al., 1991].

We have also used some of these ideas in developing a procedure for matching polygons. We have developed a distance measure between two polygons to measure their closeness in shape. This is invariant to rotation of the polygon. Details are in the journal paper [Koch and Kashyap, 1989].

A list of publications supported by the contract is given in section 2.

2. LIST OF PUBLICATIONS SUPPORTED BY ARO CONTRACT DAAL03-89-K-0032

Archival Journal Papers

[1] Yizong Cheng and R.L. Kashyap (1989), "A Study of Associative Evidential Reasoning," *IEEE Trans. on Pattern Analysis and Machine Intelligence,* Vol. 11, No. 6, pp. 623-631.

[2] K.B. Eom and R.L. Kashyap (1990), "Composite Edge Detection with Random Field Models, *IEEE Trans. on Systems, Man, and Cybernetics,* Vol. 20, No. 1, pp. 81-93.

[3] H.Y. Hau and R.L. Kashyap (1990), "Belief Combination and Propagation in Lattice Structured Inference Networks," ***IEEE Trans. on Systems, Man, and Cybernetics,*** Vol. 20, No. 1, pp. 45-57.

[4] M. Koch and R.L. Kashyap (1989), "Matching Polygon Fragments," ***Pattern Recognition Letters,*** Vol. 10, pp. 297-308.

[5] L.W. Chang and R.L. Kashyap (1989), "Study of Combination of Belief Intervals in Lattice Structured Networks," ***Intl. Journal of Man-Machine Studies,*** Vol. 30, pp. 193-211.

[6] M. Marefat and R.L. Kashyap (1990), "Geometrical Reasoning for Recognition of Three Dimensional Object Features," ***IEEE Trans. on Pattern Analysis and Machine Intelligence,*** Vol. 12, October 1990, pp. 949-964.

[7] Y. Choe and R.L. Kashyap (1991), "3D Shape from a Shaded and a Textural Surface Image," ***IEEE Trans. on Pattern Analysis and Machine Intelligence,*** Vol. 13, No. 9, pp. 907-919.

[8] S.S. Iyengar, M.B. Sharma, and R.L. Kashyap (1992), "Information Routing and Reliability Issues in Distributed Sensor Networks," ***IEEE Trans. Signal Processing,*** (accepted for publication).

[9] Jayasimha, S.S. Iyengar, and R.L. Kashyap (1991), "Information Integration and Synchronization in Distributed Sensor Networks," ***IEEE Trans. on Systems, Man, and Cybernetics,*** Vol. 21, No. 5, Sept.-Oct. 1991.

[10] L. Prasad, S.S. Iyengar, R.L. Kashyap, and R.N. Madan (1991), "Functional Characterization of Sensor Integration in Distributed Sensor Networks," ***IEEE Trans. on Systems, Man, and Cybernetics,*** Vol. 21, No. 5, Sept.-Oct. 1991.

Theses

[1] Yoonsik Choe, "Modelling, Estimation and Pattern Analysis of Random Textures on 3D Surfaces," ***Ph.D. Thesis,*** Purdue University, West Lafayette, IN, December 1990.

[2] L.W. Chang, "Uncertainty Management and Evidential Reasoning with Structured Knowledge," ***Ph.D. Thesis,*** Purdue University, West Lafayette, IN, May 1989.

[3] Hong Li, "Model and Knowledge Based Texture Segmentation," ***M.S.E.E. Thesis,*** Purdue University, West Lafayette, IN, December 1990.

Conference Papers

Army Conference on Applied Math and Computing

[1] R.L. Kashyap and K.B. Eom (invited presentation), "Robust Image Models for Image Restoration and Texture Edge Detection," *Seventh Army Conference on Applied Math and Computing,* West Point, June 1989.

[2] R.L.. Kashyap and M. Marefat, "Geometrical Reasoning for Recognition of 3-D Object Features," *Eighth Army Research Conference on Applied Math and Computing,* Cornell, June 1990. [Earlier version of the journal paper.]

[3] R.L. Kashyap and Y. Choe, "Shape from a Textured and Shaded Surface Image," *Ninth Army Research Conference on Applied Math and Computing,* June 1991 (to be presented).

Other Conferences

[4] Y. Choe and R.L. Kashyap, "A 3D Texture Model of a Natural Scene Image," *Proc. of 24th Asilomar Conference on Signals, Systems, and Computers,* Asilomar, CA, November 1990.

[5] Hong Li and R.L. Kashyap, "Texture Segmentation Based on Random Field Models and Knowledge Reasoning," *Proc. of the Allerton Conference on Circuits and Systems,* Allerton, IL, October 1990.

[6] Y. Choe and R.L. Kashyap, "Shape from Textured and Shaded Surface," *Proc. of the 10th International Con. on Pattern Recognition,* Atlantic City, NJ, June 1990. [Earlier version of the journal paper.]

3. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Mr. L.W. Chang, Ph.D. in Electrical Engineering awarded May 1989

Mr. Hong Li, completed Masters degree in Electrical Engineering, December 1990

Mr. Yoonsik Choe, completed Ph.D. degree in Electrical Engineering, December 1990

Mr. R. Maiyuran, Masters student

Ms. Birsen Yazici, Ph.D. student

Mr. Jin-Nan Liaw, Ph.D. student

4. MISCELLANEOUS INFORMATION

A. Honors

Professor R.L. Kashyap received the 1990 King-Sun Fu Research Award from the International Association of Pattern Recognition for fundamental contributions to pattern recognition and computer vision on June 18, 1990, at the 10th International Conference on Pattern Recognition. He also delivered the King-Sun Fu lecture as the plenary talk with the title "Three Decades in Pattern Recognition."

B. Contacts with U.S. Army Labs

Professor R.L. Kashyap had personal meetings and e-mail contacts with the following Army lab personnel on the research being done and its relevance for the Army:

(i) Mark Ginsberg
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(ii) Dr. Som Karamchetty
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13. ABSTRACT *(Maximum 200 words)*

This report describes fundamental contributions made in two areas mentioned in the original research proposal to ARO, namely:

a) Model based decision methods for imaqe segmentation, and
b) Robust combination of uncertain evidence from several different sources.

The results are published (or in press) in ten journal papers and several conference papers listed in section 2. The list of scientific personnel supported is in section 3.

14. SUBJECT TERMS
uncertain evidence, knowledge fusion, intelligent decision, segmentation, texture, random field models.

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