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FINAL REPORT

Contract DAAG-53-76C-0138

(DARPA Order 3206)

"Understanding Objects,
Features and Backgrounds"

Submitted to: U.S. Army Night Vision
and Electro-Optics Laboratory
Fort Belvoir, VA 22060

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ABSTRACT

Research on "Understanding Objects, Features, and Backgrounds," carried out during the period May 1980 - December 1982, is summarized under the following headings:

a) Object segmentation and recognition

b) Feature extraction and background analysis

c) Multi-resolution image analysis

d) Time-varying imagery analysis

Further details can be found in the 32 technical reports that were issued on the project; a list of these reports, together with their abstracts, is provided.

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1. Introduction

In June 1976 the U.S. Army Night Vision and Electro-Optics Laboratory awarded Contract DAAG-53-71-C-0138 to the University of Maryland for research on "Algorithms and Hardware Technology for Image Recognition." Funding for this contract was derived primarily from the Defense Advanced Research Projects Agency under DARPA Order 3206. During the following 21-month period, the University developed and tested advanced algorithms for detection of tactical targets on Forward-Looking InfraRed (FLIR) imagery. Concurrently, on a subcontract, the Westinghouse Defense Systems Division designed charge-coupled device (CCD) layouts for implementing many of these algorithms in hardware, and also fabricated a CCD chip that implemented one basic algorithm, histogramming/sorting. The results of the work done during the first 21 months of the contract are documented in detail in a Final Report dated March 1978 [A1].*

In April 1978 the contract was extended for a two-year period, under the new title "Image Understanding Using Overlays." During this phase of the project, numerous algorithms were developed and tested for object detection and extraction from images, as well as for image and region representation. On a subcontract, Westinghouse investigated the implementation of some of these algorithms in general- or special-purpose digital hardware. Westinghouse also conducted tests of one class of algorithms known as "relaxation" techniques. The results of

*Numbers in brackets refer to the report abstracts given in the Appendix.

the work done during this period are documented in a series of technical and semiannual reports, and are summarized in a Final Report dated May 1980 [A2].

In May 1980 the contract was extended for a final two-year period (later extended, at no additional cost, through December 1982), under the title "Understanding Objects, Features, and Backgrounds." During this phase of the project, further studies were conducted, in collaboration with Westinghouse, on object segmentation and recognition, feature extraction and background analysis, multi-resolution image processing techniques, and analysis of time-varying imagery. This work was documented in a series of project status reports [B1-3] and Technical Reports [C1-32], and is summarized in this Final Report.

Principal Investigators on this project at the University of Maryland were Profs. Azriel Rosenfeld and Larry S. Davis, and at Westinghouse, Dr. Glenn E. Tisdale and Mr. Bruce J. Schachter. The project monitor at NVEOL is Dr. George R. Jones.

2. <u>Object segmentation and recognition</u>

a) <u>Comparative segmentation study</u>

A comparative study of object extraction techniques applicable to FLIR imagery was conducted jointly by Maryland and Westinghouse, using a database of 52 images collected by Westinghouse from Army, Navy, and Air Force sources. Techniques tested by Maryland included two variations of a relaxation method as well as new methods based on multiresolution image representations, known as "pyramids." One of the pyramid-based methods outperformed all the other techniques tested. The results of the Maryland study are documented in detail in a technical report [C19], while Westinghouse's study is documented in a Westinghouse report.

b) <u>New segmentation techniques</u>

As a supplement to the main segmentation study, several new segmentation techniques were developed under the project. Two methods developed on earlier projects were extended from single-band to multiband imagery. One of these improves the detectability of clusters in a histogram or scatterplot by suppressing pixels that lie on edges [C1]. The other, known as "Superspike," converts the peaks in a histogram or scatterplot into sharp spikes (thus making them trivially detectable) by a process of iterated local averaging in which the histogram is used as a guide in selecting those neighbors with which a given pixel should be averaged [C26]. A third method, "bimean clustering," identifies the two "best" subpopulations in a histogram by finding the pair of values that gives a best fit to the histogram in the least squares sense [C20].

c) Object identification using constraint filtering

The conventional approach to recognizing targets in FLIR imagery is to extract potential target regions using segmentation techniques, and then carefully analyze the properties of each region independently in order to determine whether or not it could be a target. We have investigated a complementary approach based on comparisons among regions rather than analysis of individual regions. After the image is segmented, we give each region a set of possible labels - e.g., "sky," "ground," "smoke," "tree," "tank." We then attempt to eliminate labels from the regions based on their relationships with other regions (relative property values, relative positions, etc.). This method performed successfully in a small set of tests; it eliminated the "tank" label from all the non-tank regions but kept it for all the tank regions [C25]. This approach should be of interest as a supplement to existing target recognition algorithms.

3. Feature extraction and background analysis

a) Edge and corner extraction

Feature detection (e.g., edge detection) is an important adjunct to object recognition, and also plays an important role in image matching (e.g., for object tracking and time-varying imagery analysis). Three feature detection studies were conducted on this project. The optimal approach to edge detection developed by Hueckel, which finds the best-fitting step function to a given image neighborhood, was applied to derive optimal edge operators for a class of small neighborhoods [C28]. A basic new method of evaluating edge detector output, based on consistency of the edge output data, was developed and successfully tested [C8]. A simplified method of corner detection was developed based on detecting discontinuities in one-dimensional projections of the image; this method eliminates the need to apply computationally expensive higher-order derivative operators at every point of the image [C13].

b) Blob and ribbon extraction

Work was also done on the detection of higher-level features such as "blobs" and "ribbons" in an image. (A blob is surrounded by consistently facing edges, while a ribbon is characterized by "antiparallel," oppositely facing edges.) Edge linking schemes were developed for detecting such features based on compatibility of the edges with respect to both geometry and gray level [C2].

Quantitative measures for edge compatibility were also developed for assessing both closedness [C3] and anti-parallelness [C4].

c) Texture analysis

In connection with image background characterization, two texture analysis studies were conducted. An approach to texture analysis based on average strength of match with various local patterns was implemented; it was found to perform better than several standard methods [C18]. The idea of applying texture measures to arrays of terrain elevation data was also briefly explored; if such data were available at sufficient resolution, it would provide a useful supplement to intensity-based texture analysis [C15].

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4. Multi-resolution image analysis

a) Background and related work

A potentially powerful new approach to image analysis, now under development at our laboratory, is based on the use of a "pyramid" of successively reduced-resolution versions of the given image. Initial work on image segmentation using pyramids was done under NSF sponsorship. During the summer of 1982, a workshop on "Multiresolution Image Processing and Analysis" was held, also under NSF sponsorship, at which about 25 research groups presented recent results that make use of multiresolution image representations in various ways. The pyramid image representation also has the advantage of compatibility with the quadtree region representation, which was extensively studied during an earlier phase of this project, and which is being further studied in connection with cartographic data base applications under the sponsorship of the U.S. Army Engineer Topographic Laboratory.

b) Segmentation and representation

One way of using the pyramid representation in image segmentation is to define links between pixels and their "parents" at consecutive levels of the pyramid, based on mutual similarity; this gives rise to subtrees of the pyramid, and thus defines a partition of the image, where each part consists of the pixels that are the leaves of a given subtree. A number of variations on this basic approach were investigated [C6], and it was also generalized to multispectral imagery [C11]. In connection with quadtree region representation, earlier work on the generation of an image row by row from its quadtree was extended to include several new algorithms [C7].

c) Feature extraction and encoding

Pyramids can also be used to extract and represent features such as edges and blobs in an image. If we use mutual similarity as a basic for linking "edgels," rather than pixels, in a pyramid representation, we obtain "trees" of edges which allow us to detect the major edges in an image, at the higher levels of the pyramid, and then locate these edges precisely at the full-resolution level [C14]. Pyramids can also be used to encode edges (or curves) detected in an image, yielding successively coarser approximations as long as the edges crossing a given block of the image can be compactly approximated [C5]. These approximations can then be used as an aid in linking together edge segments that lie on long lines or smooth curves [C30]. Two approaches to blob extraction using pyramids were also investigated. One of these uses pixel linking to construct subtrees of the pyramid such that leaves of each subtree are the pixels that belong to a compact, homogeneous piece of the image [C24]. Another approach is based on the fact that any blob shrinks to a (local) "spot" at some level of the pyramid; it detects blobs by constructing an edge pyramid and detecting pixels that are locally surrounded by edges [C21]. This method outperformed all the others that were tested in the comparative study of FLIR image segmentation techniques (see above, Section 2a).

5. Time-varying imagery analysis

a) Image matching

One approach to detecting and analyzing motion in an image sequence is to identify sets of corresponding points in successive frames of the sequence. This is usually done by searching for matches to pieces of one frame in the other frame. In order to obtain sharp matches, it is desirable to use pieces that contain distinctive, high-contrast features such as corners (they are preferable to edges because the match to an edge is insensitive to displacement in the direction along the edge). Some successful experiments in image matching using corner features are described in [C12]. A supplemental experiment, reported in [C17], showed that local intensity-based matching in the neighborhood of a feature point can be used to unambiguously locate match peaks in those cases where the results of feature matching are ambiguous.

b) Motion estimation and smoothing

Another approach to motion detection, appropriate in cases where the rate of motion does not exceed one pixel per frame, involves using the space and time derivatives of the image intensity at each pixel to estimate a motion vector at that pixel. This method yields reliable estimates of motion components only in directions where there are rapid changes in gray level. Thus in a smooth region it yields no useful information; at an edge it yields only the component of motion in the direction across the edge; but at corner pixels it yields two components, thus allowing the entire motion vector to be estimated [C16]. Given a region in the image representing a rigid object moving parallel to the image plane, we can estimate motion vectors at the corners of the object and "propagate" these estimates around the edges of the object to determine its motion (translation and rotation). This approach to motion estimation was developed in a series of reports [C22,C23,C29].

The motion vector fields obtained from small image neighborhoods are noisy. If they are smoothed by simple local averaging, incorrect results are obtained at the boundaries of moving objects. A better approach is to use nonlinear smoothing techniques based on selective local averaging; this does not blur sharp edges [C31]. A related problem is that of smoothing the images in a sequence by averaging successive frames; here one cannot simply average corresponding pixels, but must introduce displacements in order to allow for the motion. In this connection, one need not know the entire motion vector, but only its component in the gradient direction, since errors in the tangential direction will not cause edges to become blurred [C32].

c) Optical flow analysis

The changes in an image sequence due to the motion of the observer relative to the scene, rather than to object motion, are known as "optical flow." Given an array of motion vectors representing optical flow, methods have been developed of inferring the parameters of the observer's motion (translational and rotational) and of deriving the relative distances between the observer and the points in the scene. Algorithms for deriving relative scene distance and local surface orientation from optical flow are presented in [C9], while a method of deriving the observer's instantaneous direction of motion from optical flow, and of decomposing his motion into translational and rotational components, is developed in [C10].

6. Status reports

As mentioned in the Introduction, three project status reports were issued [B1-3] that summarize the work done during this phase of the project. The first and third of these reports were also published in the Proceedings of the two DARPA Image Understanding Workshops that were held during this period (April 1981 and September 1982).

At a meeting of the principal investigators on the DARPA Image Understanding Program, held in January 1982, it was decided to prepare a Final Report on the overall program. The University of Maryland was asked to draft the portion of this report dealing with two-dimensional image analysis techniques ("low-level vision"). An edited version of this draft was also issued as a technical report [C27].

APPENDIX: REPORT ABSTRACTS

A. Final Reports on previous phases of the project

1. Final report: Algorithms and hardware technology for image recognition, March 1978.

ABSTRACT: Algorithms for detecting and classifying tactical targets on forward-looking infrared (FLIR) imagery were developed. A Westinghouse subcontract investigated the implementability of these algorithms in charge-coupled device (CCD) technology, and also successfully implemented one basic function, sorting.

2. Final report: Image understanding using overlays, May 1980.

ABSTRACT: This report summarizes accomplishments on the project during the period 1 October 1979 - 30 March 1980 under three headings: (1) segmentation and texture analysis; (2) local and global shape analysis; (3) hierarchical representation. It also describes the efforts to be conducted during the next two-year phase of the project, under the title "Understanding Features, Objects, and Backgrounds," and provides a listing of all the reports issued and papers published during the two-year phase just completed.

B. Interim Reports on the current phase of the project

1. Semi-annual report (1 April 1980 - 31 January 1981), February 1981.

ABSTRACT: Current activities on the project are reviewed under the following headings: (1) segmentation, (2) local feature detection, (3) feature linking, and (4) hierarchical representation.

2. Semi-annual report (1 February - 31 July 1981), August 1981.

ABSTRACT: Current activities on the project are reviewed under the following headings: (1) segmentation, (2) local feature detection and matching, (3) hierarchical representation.

3. Project status report (1 August 1981 - 31 July 1982), July 1982.

ABSTRACT: Current activities on the project are summarized under the following headings: (a) preprocessing and segmentation, (b) feature detection and texture analysis, (c) hierarchical representations, (d) matching and motion.

C. Technical Reports on the current phase of the project

1. Alan Broder and Azriel Rosenfeld, "Gradient Magnitude as an Aid in Color Pixel Classification". TR-906, DAAG-53-76C-0138, June 1980.

ABSTRACT: When pixels in a black-and-white image are classified by thresholding their gray levels, gradient magnitude information can be used in various ways as an aid in threshold selection. This note deals with the use of color gradient magnitude as an aid in classifying pixels based on their colors or spectral signatures.

2. Mohamad Tavakoli and Azriel Rosenfeld, "Toward the Recognition of Buildings and Roads on Aerial Photographs". TR-913, DAAG-53-76C-0138, July 1980.

ABSTRACT: This paper describes steps toward the recognition of cultural features such as buildings and roads on aerial photographs. The approach involves several successive stages of grouping of edge segments. Straight line segments are fitted to sets of edge pixels; compatibilities between pairs of these segments, based on gray level and geometric information, are computed; and the segments are then grouped into building-like and road-like groupings based on these compatibilities. Examples of the results obtained using this approach are given, and some variations on the initial stages of the process are also investigated.

3. Mohamad Tavakoli and Azriel Rosenfeld, "A Method for Linking Pairs of Compatible Linear Features". TR-930, DAAG-53-76C-0138, August 1980.

ABSTRACT: A method of linking compatible straight edges is presented and discussed. The linking is based on information about the geometrical configuration of the edges, the similarity of the gray levels on their object sides, and the similarity of their object sides with the line joining their endpoints. Three figures of merit are defined for evaluating pairs of segments for possible linking. Examples are shown of applying the method to high resolution aerial photographs. Results indicate that cultural features such as roads and buildings can be extracted and that a significant reduction in the complexity of the image description can be obtained. This approach should be especially useful for defining the degrees of compatibility of pairs of edges in a relaxation scheme for classifying linear feature segments.

4. Mohamad Tavakoli and Azriel Rosenfeld, "A Method for Finding Pairs of Anti-Parallel Linear Features." TR-943, DAAG-53-76C-0138, September 1980.

ABSTRACT: A method for finding anti-parallel straight edges is presented and discussed. This method is based on information about the object sides of edges, the similarity and homogeneity of gray level between the edges, the angle difference, the amount of overlap, and also information about the estimated object gray level. Two figures of merit are defined to calculate the mutual support of two antiparallel linear features. Examples are shown of applying the method to high resolution aerial photographs. Results indicate that cultural features such as roads and buildings can be extracted and that a significant reduction in the complexity of the image description can be obtained. This algorithm should be especially useful in a relaxation type scheme for classifying linear feature segments when the degree of anti-parallelism of the segments is needed.

5. Michael Shneier, "Two Hierarchical Linear Feature Representations: Edge Pyramids and Edge Quadtrees." TR-961, DAAG-53-76C-0138, October 1980.

ABSTRACT: Two related methods for the hierarchical representation of curve information are presented. First, edge pyramids are defined and discussed. An edge pyramid is a sequence of successively lower resolution images, each image containing a summary of the edge or curve information in its predecessor. This summary includes the average magnitude and direction in a neighborhood of the preceding image, as well as an intercept in that neighborhood and a measure of the error in the direction estimate. An edge quadtree is a variable-resolution representation of the linear information in the image. It is constructed by recursively splitting the image into quadrants based on magnitude, direction and intercept information. Advantages of the edge quadtree representation are its ability to represent several linear features in a single tree, its registration with the original image, and its ability to perform many common operations efficiently.

6. Teresa Silberberg, Shmuel Peleg, and Azriel Rosenfeld, "Multi-Resolution Pixel Linking for Image Smoothing and Segmentation." TR-977, DAAG-53-76C-0138, November 1980.

ABSTRACT: When an image is smoothed using small blocks or neighborhoods, the results may be somewhat unreliable due to the effects of noise on small samples. When larger blocks are used, the samples become more reliable, but they are more likely to be mixed, since a large block will often not be contained in a single region of the image. A compromise approach is to use several block sizes, representing versions of the image at several resolutions, and to carry out the smoothing by means of a cooperative

process based on links between blocks of adjacent sizes. These links define "block trees" which segment the image into regions, not necessarily connected, over which smoothing takes place. In this paper, a number of variations on the basic block linking approach are investigated, and some tentative conclusions are drawn regarding preferred methods of initializing the process and of defining the links, yielding improvements over the originally proposed method.

7. Hanan Samet, "Algorithms for the Conversion of Quadtrees to Rasters." TR-979, DAAG-53-76C-0138, November 1980.

ABSTRACT: A number of algorithms are presented for obtaining a raster representation for an image given its quadtree. The algorithms are given in an evolutionary manner starting with the straightforward top-down approach that visits each run in a row in succession starting at the root of the tree. The remaining algorithms proceed in a manner akin to an inorder tree traversal. All of the algorithms are analyzed and an indication is given as to when each is preferable. The execution time of all of the algorithms is shown to be proportional to the sum of the heights of the blocks comprising the image.

8. Les Kitchen and Azriel Rosenfeld, "Edge Evaluation Using Local Edge Coherence." TR-981, DAAG-53-76C-0138, December 1980.

ABSTRACT: A method of evaluating edge detector output is proposed, based on the local good form of the detected edges. It combines two desirable qualities of well-formed edges -- good continuation and thinness. The measure has the expected behavior for known input edges as a function of their blur and noise. It yields results generally similar to those obtained with measures based on discrepancy of the detected edges from their known ideal positions, but it has the advantage of not requiring ideal positions to be known. It can be used as an aid to threshold selection in edge detection (pick the threshold that maximized the measure), as a basis for comparing the performances of different detectors, and as a measure of the effectiveness of various types of preprocessing operations facilitating edge detection.

9. K. Prazdny, "Relative Depth and Local Surface Orientation from Image Motions." TR-996, DAAG-53-76C-0138, January 1981.

ABSTRACT: A simple mathematical formalism is presented suggesting a mechanism for computing relative depth of any two texture elements characterized by the same relative motion parameters. The method is based on a ratio of a function of the angular velocities of the projecting rays corresponding to the two texture elements. The angular velocity of a ray cannot, however, be computed directly from the instantaneous characterization of motion of a "retinal" point. It is shown how it can be obtained from the (linear) velocity of the image element on the projection surface and the first time derivative of its direction vector. A similar analysis produces a set of equations which directly yield local surface orientation relative to a given visual direction. The variables involved are scalar quantities directly measurable on the projection surface but, unlike the case of relative depth, the direction of (instantaneous) motion has to be computed by different means before the method can be applied. The relative merits of the two formalisms are briefly discussed.

10. K. Prazdny, "Determining the Instantaneous Direction of Motion from Optical Flow Generated by a Curvilinearly Moving Observer." TR-1009, DAAG-53-76C-0138, February 1981.

ABSTRACT: A method is described capable of decomposing the optical flow into its rotational and translational components. The translational component is extracted implicitly by locating the focus of expansion associated with the translational component of the relative motion. The method is simple, relying on minimizing an (error) function of 3 parameters. As such, it can also be applied without modification, in the case of noisy input information. Unlike the previous attempts at interpreting optical flow to obtain information about the three-dimensional disposition of texture elements, the method uses only relationships between quantities on the projection plane. No 3D geometry is involved. Also outlined is a possible use of the method for the extraction of that part of the optical flow containing information about relative depth directly from the image intensity values, without extracting the "retinal" velocity vectors.

11. Tsai-Hong Hong and Azriel Rosenfeld, "Multiband Pyramid Linking." TR-1025, DAAG-53-76C-1038, March 1981.

ABSTRACT: A method of image segmentation has been developed based on creating links between pixels in successive layers of a "pyramid" of reduced-resolution versions of the image. In the original implementation of this method, the links were based on comparing the values of a single feature, (average) gray level, for each pixel. In this note, the method is extended to links based on multiple features, such as color components or neighborhood properties.

12. Cheng-ye Wang, Hanfang Sun, Shiro Yada, and Azriel Rosenfeld, "Some Experiments in Relaxation Image Matching Using Corner Features." TR-1071, DAAG-53-76C-0138, July 1981.

ABSTRACT: A relaxation method based on patterns of local features is used to find matches between pairs of images or subimages that differ in position or orientation. A local operator is applied to the two images to detect two sets of "corners" $C_1,...,C_m$ and $D_1,...,D_n$, each of them characterized by position, orientation, contrast, and "sharpness" (of the angle). For each pair (C_i,D_j), a figure of merit is computed, and a relaxation process is used to iteratively adjust these figures of merit, based on the merits of other pairs in approximately corresponding positions. After a few iterations of this process, "good" matches (pairs having much better merit than their next best choices) are clustered, yielding sets of transformation parameters (shift vectors or rotation angles) under which many corners correspond. This method has yielded good results for TV images of objects such as tools and industrial parts, as well as for aerial images of terrain.

13. Zhong-Quan Wu and Azriel Rosenfeld, "Filtered Projections as an Aid in Corner Detection." TR-1078, DAAG-53-76C-0138, July 1981.

ABSTRACT: Corners are very useful features for such purposes as image matching or shape analysis, but corner detection is a relatively expensive operation. This paper uses filtered x and y projections, applied to an image containing an object that nas not been explicitly segmented from its background, to determine possible positions of corners, so that corner detection can be applied only in the vicinity of these positions. Even in cases where the object would be hard to segment (unimodal histogram), this approach yields a good set of possible corner positions.

14. T. H. Hong, M. Shneier, and A. Rosenfeld, "Border Extraction Using Linked Edge Pyramids." TR-1080, DAAG-53-76C-0138, July 1981.

ABSTRACT: Borders of objects in a noisy image can be cleanly extracted by a parallel procedure involving links between edge points in a pyramid of reduced-resolution versions of the image.

15. Cheng-Ye Wang and Azriel Rosenfeld, "Elevation Texture." TR-1086, DAAG-53-76C-0138, August 1981.

ABSTRACT: Given an array of terrain elevation values, texture analysis techniques can be used, in principle, for segmentation and terrain type classification.

16. K. Prazdny, "Computing Motions of (Locally) Planar Surfaces from Spatio-Temporal Changes in Image Brightness: A Note." TR-1090, DAAG-53-76C-0138, August 1981.

ABSTRACT: The motion at a locus on the projection surface cannot be obtained locally from spatio-temporal changes in image intensity at that locus. If the imaged surfaces are (locally) planar, however, and generate a set of non-parallel straight line edges in the image, it is possible to obtain estimates of image velocities of a set of image points corresponding to the intersections of the lines. The availability of such a (small) set is sufficient to resolve the underlying optical flow into its translational and rotational components.

17. Hanfang Sun, "Image Registration by Combining Feature Matching and Gray Level Correlation." TR-1091, DAAG-53-76C-0138, August 1981.

ABSTRACT: A method of image registration based on matching patterns of local features was described in an earlier report. This note describes the use of gray level correlation to handle cases in which feature matching gives ambiguous results. Substantial improvement in matching performance can be achieved at little additional computational cost.

18. Matti Pietikäinen, Azriel Rosenfeld, and Larry S. Davis, "Texture Classification Using Averages of Local Pattern Matches." TR-1098, DAAG-53-76C-0138, September 1981.

ABSTRACT: Laws has introduced a class of texture features based on average degrees of match of the pixel neighborhoods with a set of standard masks. These features yield better texture classification than standard features based on pairs of pixels. This paper investigates simplifications of these features, and shows that their performance is not greatly affected by their exact form, and also appears to remain the same if only local match maxima are used. It also presents an alternative definition of such features based on sums and differences of Gaussian convolutions.

19. Ralph L. Hartley, Leslie J. Kitchen, Cheng-Ye Wang, and Azriel Rosenfeld, "A Comparative Study of Segmentation Algorithms for FLIR Images." TR-1104, DAAG-53-76-C-0138, September 1981.

ABSTRACT: A comparative study of FLIR segmentation algorithms has been conducted in cooperation with Westinghouse Defense Systems Division. In the Maryland portion of the study, four techniques (two- and three-class relaxation, "pyramid linking", and "superspike") were tested on a Westinghouse-supplied database of 51 images obtained from NVL and other sources. (Two other techniques, "superslice" and "pyramid spot detection", were rejected after preliminary studies.) The best technique, "superspike", extracted regions corresponding to over 88% of the targets, and had a false alarm rate of 1.6 false regions per true target.

20. Stanley Dunn, Ludvik Janos, and Azriel Rosenfeld, "Bi-mean Clustering." TR-1106, DAAG-53-76-C-0138, September 1981.

ABSTRACT: An algorithm is presented which finds the best-fitting pair of constants, in the least squares sense, to a set of scalar data; we call this pair of constants the "bimean" of the data. The relationship of the bimean clustering to the ISODATA clustering algorithm, and its application to image thresholding, are also discussed.

21. T. H. Hong and M. Shneier, "Extracting Compact Objects Using Linked Pyramids." TR-1123, DAAG-53-76C-0138, November 1981.

ABSTRACT: Compact objects of arbitrary size are extracted from images using a combination of three pyramid-based representations of image features. A gray-scale linked pyramid is used to smooth the image into uniform regions. A "surroundedness" pyramid is used to identify regions of interest, and a linked edge pyramid is used to delimit the boundaries of the compact objects.

22. Larry S. Davis, Hanfang Sun, and Zhongquan Wu, "Motion Detection at Corners." TR-1130, DAAG-53-76-C-0138, December 1981.

ABSTRACT: A method for directly computing image motion at corners is presented. The method is based on temporal intensity gradients along lines parallel to the sides of the corner. The results of applying the method to two time-varying images are discussed.

23. Zhongquan Wu, Hanfang Sun, and Larry S. Davis, "Determining Velocities by Propagation." TR-1132, DAAG-53-76C-0138, December 1981.

ABSTRACT: A velocity propagation technique is described that determines velocity vectors at the points of a contour, based on the velocities at the endpoints of the contour and the normal components of velocity along the contour.

24. Tsai-Hong Hong and Azriel Rosenfeld, "Unforced Image Partitioning by Weighted Pyramid Linking." TR-1137, DAAG-53-76C-0138, January 1982.

ABSTRACT: This paper describes a method of image segmentation that creates a partition of the image into compact, homogeneous regions using a parallel, iterative approach that does not require immediate forced choices. The approach makes use of a "pyramid" of successively reduced-resolution versions of the image. It defines link strengths between pairs of pixels at successive levels of this pyramid, based on proximity and similarity, and iteratively recomputes the pixel values and adjusts the link strengths. After a few iterations, the link strengths stabilize, and the links that remain strong

25. Les Kitchen, "Scene Analysis Using Region-Based Constraint Filtering." TR-1150, DAAG-53-76C-0138, February 1982.

ABSTRACT: A general-purpose scene-analysis system is described which uses constraint-filtering techniques to apply domain knowledge in the interpretation of the regions extracted from a segmented image. An example is given of the configuration of the system for a particular domain, FLIR (Forward Looking InfraRed) images, as well as results of the system's performance on some typical images from this domain.

26. Cheng-Ye Wang and Leslie Kitchen, "Improvements in Multispectral Image Smoothing." TR-1152, DAAG-53-76-0138, March 1982.

ABSTRACT: Two problems with the multispectral smoothing technique of Pietikainen and Rosenfeld are that random sampling fluctuations in the scatter plot may produce spurious pixel classes, and that noise pixels sufficiently distinct from their neighbors will not be smoothed at all. These problems can be overcome by the use of variable-neighborhood smoothing in the scatterplot, and by a judicious use of median filtering in conjunction with multispectral smoothing.

27. Azriel Rosenfeld, "Computer Vision." TR-1157, DAAG-53-76C-0138, April 1982.

ABSTRACT: Computer vision deals with the analysis and interpretation of images. Over the past 25 years, many ad hoc techniques for analyzing images have been developed, but during the past few years this technology has begun to develop a scientific basis. This paper outlines the major components of a general computer vision system, and summarizes the state of the art in each of these components.

28. Ravi B. Boppana and Azriel Rosenfeld, "Some Properties of Hueckel-Type Edge Operators." TR-1178, DAAG-53-76C-0138, June 1982.

ABSTRACT: Hueckel-type edge operators find the best-fitting step function to a given image neighborhood. This note derives some basic properties of such operators for various classes of neighborhoods.

29. Larry S. Davis, Zhongguan Wu and Hanfang Sun, "Contour-based Motion Estimation." TR-1179, DAAG-53-76C-0138, June 1982.

ABSTRACT: This paper introduces a contour-based approach to motion estimation. It is based on first computing motion at image corners, and then propagating the corner motion estimates along the principal contours in the image based on a local 2 1/2D motion assumption. The results of several experiments are presented.

30. T. H. Hong, M. Shneier, R. Hartley and A. Rosenfeld, "Using Pyramids to Detect Good Continuation." TR-1185, DAAG-53-76C-0138, July 1982.

ABSTRACT: Pictures containing lines and curves are often perceived by humans as being composed of a smaller number of more global figures. For example, a broken set of collinear line segments is perceived as a single straight line, even in the presence of other overlapping line segments. This paper presents a method of extracting such figures from images automatically in a highly parallel manner. A pyramid of successively lower-resolution images is used to transform the problem from one of global search to one of local good continuation. Using the pyramid, figures that are both sparse and obscured can successfully be extracted and the background clutter can be suppressed.

31. Kwangyoen Wohn, Larry S. Davis and Philip Thrift, "Motion Estimation Based on Multiple Local Constraints and Nonlinear Smoothing." TR-1188, DAAG 53-76C-0138, August 1982.

ABSTRACT: A new algorithm for estimating motion from image sequences is presented. Initial motion estimates are determined based on a least-squares solution to a set of independent linear constraints on the motion at a pixel. These initial estimates are then improved by a nonlinear smoothing operation. The results of this algorithm are compared with those obtained by the Horn-Schunck algorithm [10] on a number of image sequences.

32. Larry S. Davis, Hu-chen Xie and Azriel Rosenfeld, "Image Sequence Enhancement Based on The Normal Component of Image Motion." TR-1189, DAAG-53-76C-0138, July 1982.

ABSTRACT: Huang and Hsu [1] describe an image sequence enhancement algorithm based on computing motion vectors between successive frames and using these vectors to determine the correspondence between pixels for frame averaging. In this note, we demonstrate that it may be sufficient to use only the components of the motion vectors in the gradient direction (called the normal components) to perform the enhancement.

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Object segmentation and recognition
Feature extraction and background analysis
Multi-resolution image analysis
Time-varying imagery analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Research on "Understanding Objects, Features, and Backgrounds," carried out during the period May 1980 - December 1982, is summarized under the following headings:

a) Object segmentation and recognition
b) Feature extraction and backround analysis
c) Multi-resolution image analysis
d) Time-varying imagery analysis

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