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Research to Support Intelligent Data Management

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Introduction

The number of images including remote sensing data, mammograms, CAT scans, NMR's, fingerprints, commercial radar, etc., generated daily in both the public and the private sector is increasing dramatically. Digital scanners and other devices are used to convert these images to digital arrays allowing them to be represented on a computer. Furthermore, digitized images are transmitted over various channels of communication and stored on computers and other mass storage devices, such as CD's and external disks. Storage and transmission of such data requires large capacity and/or bandwidth that can be cost prohibitive. Hence, full and timely utilization of this large database of images requires efficient storage and retrieval. Image compression where an image can be stored in 5% or less of its original size with no loss of essential information has had a great impact on these problems.

In image processing systems, frequently a problem arises when images taken at different times, by different sensors, and/or from different viewing points need to be compared. These images need to be aligned with one another in order to detect the differences between them. A similar problem occurs when searching for a template or prototype in another image. The proper alignment between the image and the template must be found in order to obtain the optimal match for the template. Such problems can be solved by methods that perform image registration. For performing registration, a transformation must be obtained to relate the ground control points (features in the image that are employed for registration) in one image to their corresponding points in the other image.

During future earth and space missions large amounts of remotely sensed data with diverse temporal, spatial and spectral components will be obtained. Hence, the need for fast, accurate, and reliable compression and registration techniques will grow increasingly. As a consequence, during the first two years of this contract, KT-Tech's NASA COTR directed KT-Tech to the area of registration of such data.

During the second year of contract, the COTR directed KT-Tech to lead the task of porting the RVC software system (which included the major modules of user interface, ingest, planner/scheduler/dispatcher and its curator submodule, and database) from the original HP environment to a more generic SUN UNIX environment. Since KT-Tech had developed core expertise in software prototyping, test and evaluation, the COTR utilized KT-Tech in the trusted high-level position to comprehend the system design, overall logic of the RVC system, and to ensure the robustness of the modularized system for porting to numerous environments. The KT-Tech document "RVC Software Module Improvement Report" (in Appendix A) which specified the requirements for the porting activity in the context of the entire RVC system, was evaluated by the COTR as an important and pivotal initial document for the RVC documentation of requirements and specifications. By September 1997, KT-Tech successfully completed the initial porting onto a SUN environment, and this accomplishment was announced with a technical briefing at the NASA/Goddard Code 935 RVC Workshop. KT-Tech continued porting the software modules as new versions became available, and prepared the interfaces for potential porting to SGI UNIX, Windows NT and LINUX systems which the government was considering for potential future environments.

In the following sections, yearly contract performance, the results obtained and the analysis of the results will be presented.

Contract Performance and Analysis of the Results Obtained During Year 1

Employing satellite imagery, during the period April 18 - April 30, 1995, KT-Tech began investigating the application of the morphological image operators for feature extraction and the application of wavelet techniques for compression and registration of multi sensor data.

As a part of its contract deliverable with NASA, during the period May 1 - May 31, 1995, KT-Tech implemented the Lerner Algebraic Edge Detector (LAED) on a massively parallel computer, e.g. MasPar MP-1. The algorithm was applied to satellite imagery and the quantitative analysis of the results obtained by the LAED and other conventional edge detection algorithms, such as Sobel and Prewitt edge detectors, were performed.

During the period June 1 - June 30, 1995, KT-Tech implemented, as a part of its contract deliverable with NASA, the Lerner Algebraic Edge Detector (LAED) on its Sun Sparc IPX workstation in order to perform the analysis of the remote sensing data obtained from NASA locally. In addition to the LAED, conventional edge detectors such as Sobel and Prewitt edge detectors were realized on the Sun Sparc IPX workstation for comparison purposes. The algorithms were applied to composed imagery (Hannah with Hat) and satellite imagery (Pacific Northwest) and a comparative analysis of the results obtained by the LAED and the other conventional edge detection algorithms, Sobel and Prewitt edge detectors, were performed.

In Figures 1-4, the original Pacific Northwest image, and the results obtained by applying the LAED, Sobel, and Prewitt edge detectors to that image are illustrated.

As a part of its contract deliverable with NASA, during the period July 1 - July 31, 1995, KT-Tech developed a registration scheme that relates the ground control points in one image to their corresponding points in the other image in the following manner: KT-Tech developed a rotation algorithm that rotates the preprocessed input image by a given angle δ and a cross-correlation algorithm that measures the similarity between the preprocessed and rotated input
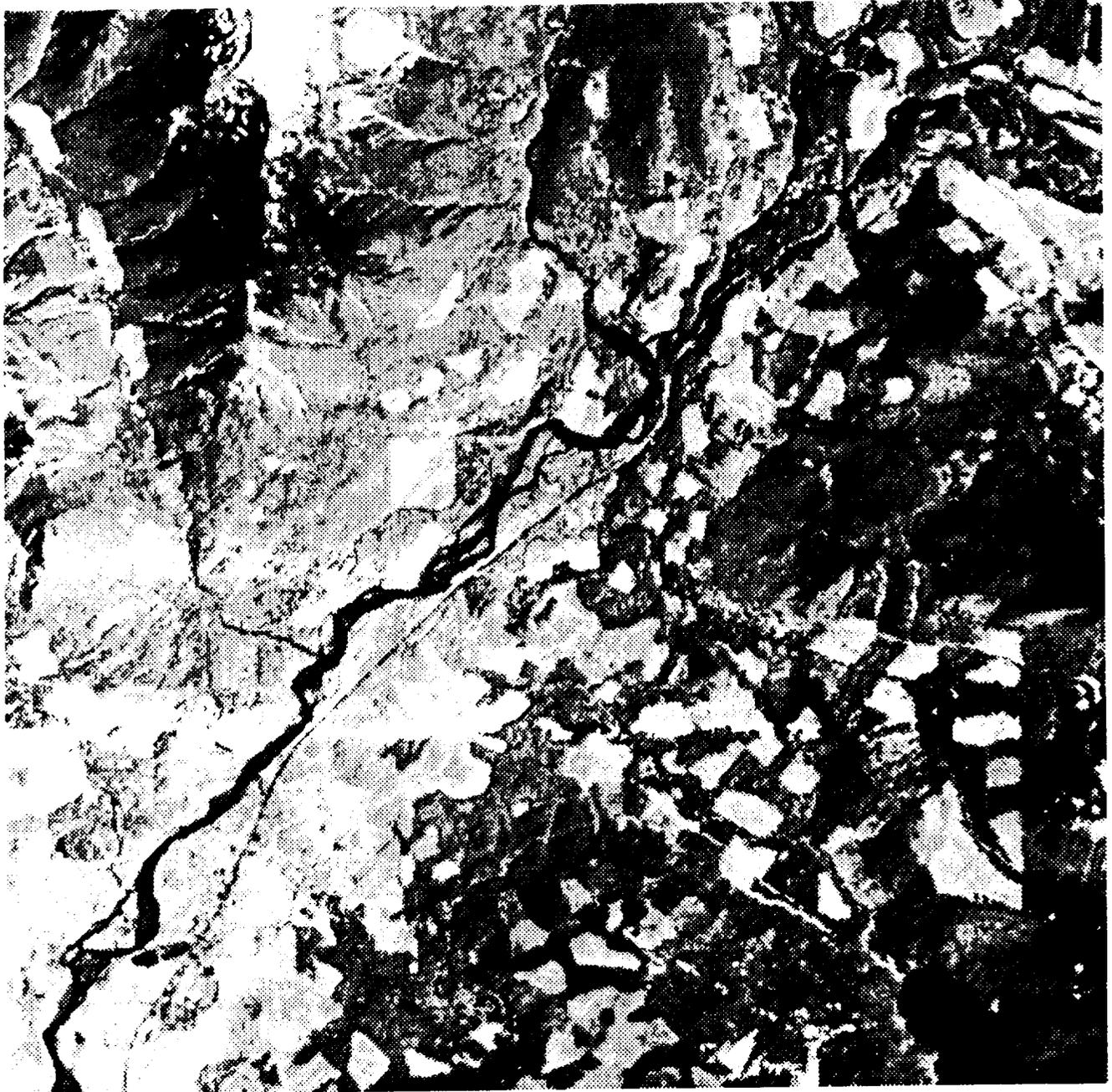
Figure 1. Pacific Northwest (original)
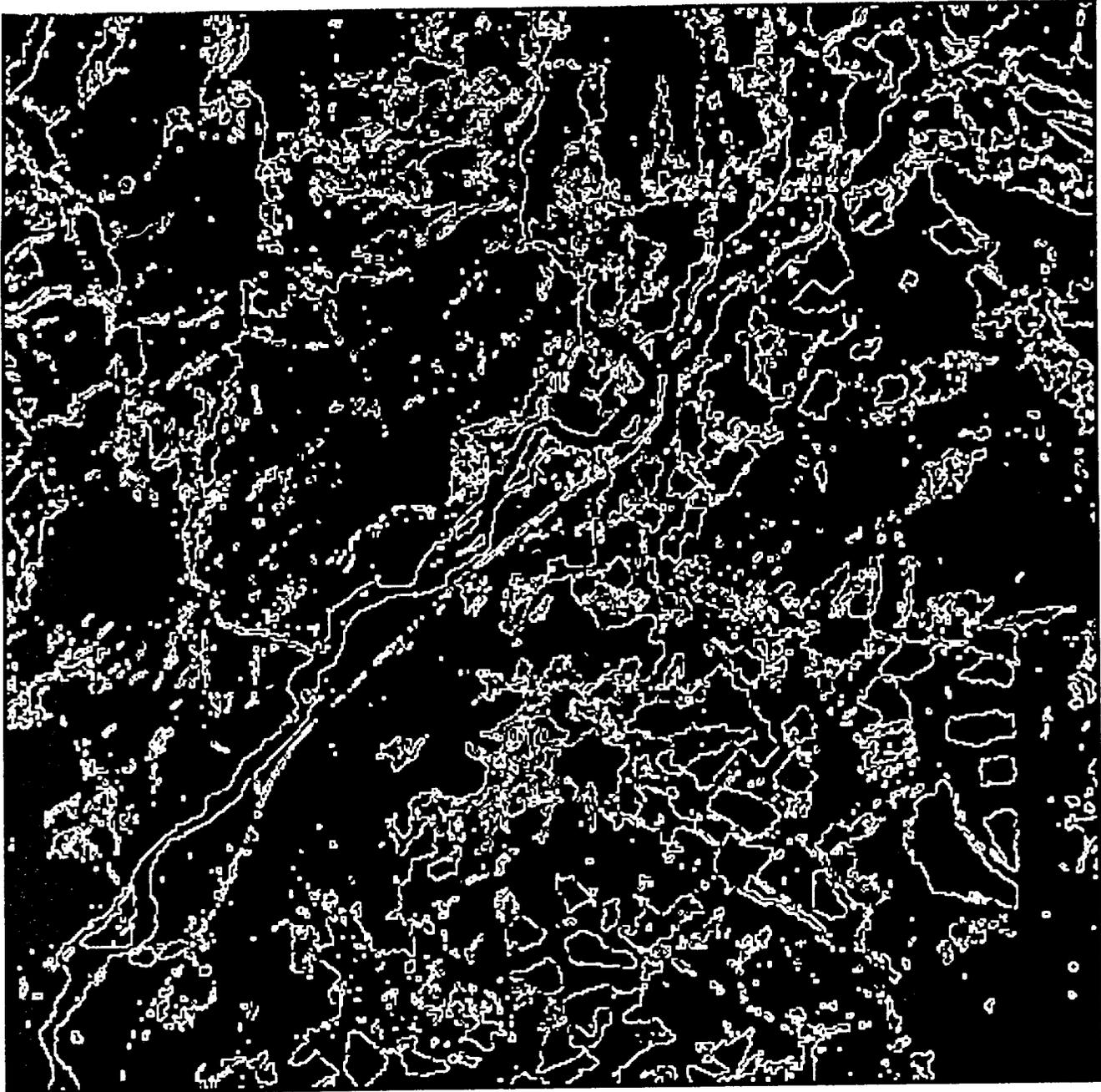
Figure 2. Pacific Northwest (LAED/thresholded)
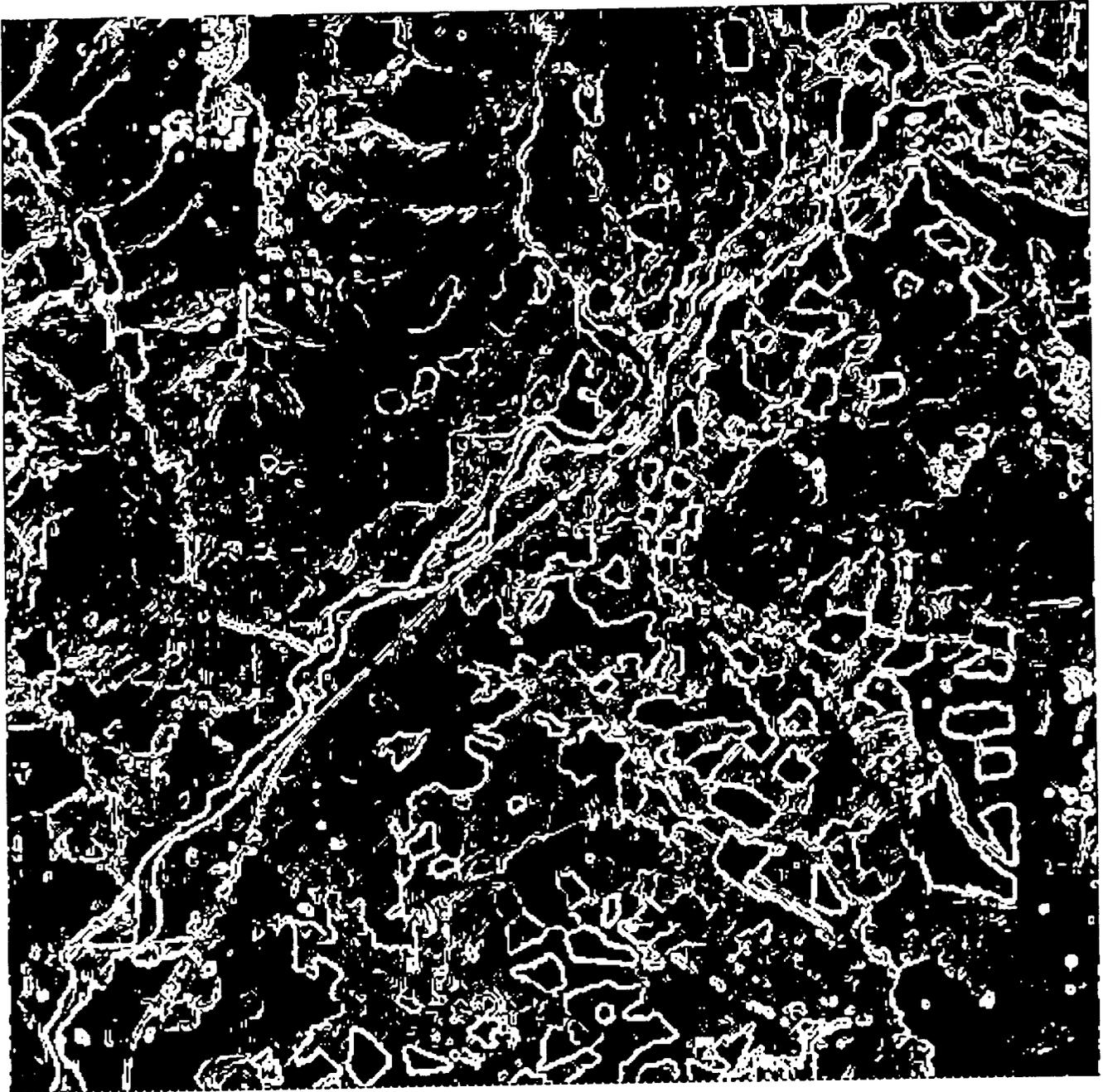
Figure 3. Pacific Northwest (Sobel edge detector/thresholded)

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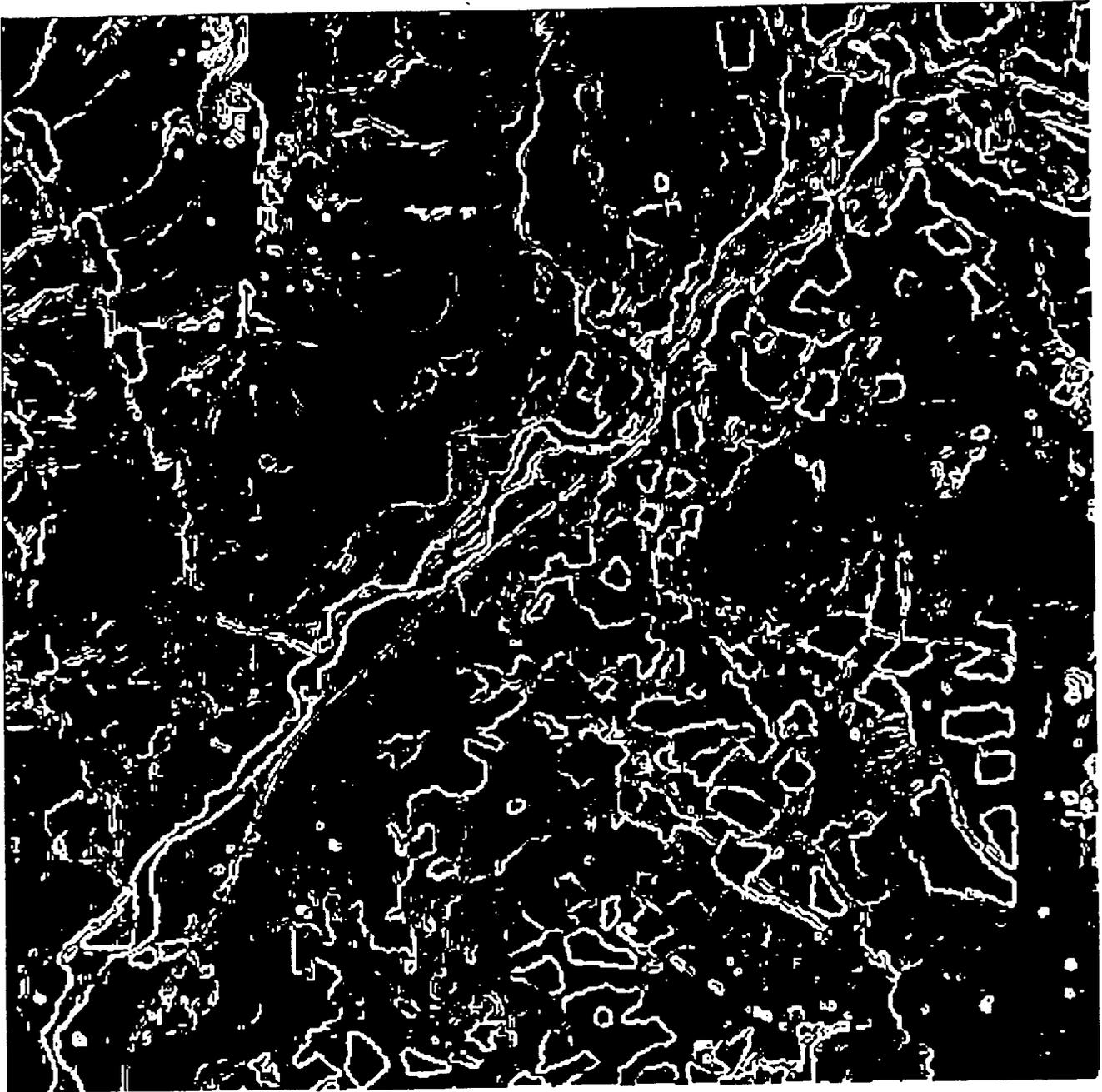
Figure 4. Pacific Northwest (Prewitt edge detector/thresholded)

image, and the preprocessed reference image. The cross-correlation between the preprocessed input and reference images is computed for a sequence of rotation angles ($0°$, ..., $90°$) and the actual angle of rotation is determined by the highest cross-correlation value. KT-Tech compared the performances of the LAED, Sobel, and Prewitt edge detectors within this registration scheme by preprocessing a reference Pacific Northwest image and an input image that is the rotated version of the reference image by a given angle, $\theta=18°$ by these edge detectors to extract the most significant information in these images.During the same period, KT-Tech developed on its Sun Sparc IPX workstation image enhancement techniques, such as histogram equalization and median filtering, to utilize in conjunction with edge detection operators.

During the period August 1 - August 31, 1995, KT-Tech started investigating multiresolution approaches, in particular the wavelet decomposition technique, to reduce the size of the images to be utilized in the registration process, and consequently, to decrease the time required for computations. KT-Tech also started studying Khoros 2.0 Scientific Software Development Environment for code development.

During the period September 1 - September 30, 1995, KT-Tech continued investigating the wavelet decomposition technique in the context of registration. KT-Tech started constructing a decomposition algorithm based on the Discrete Wavelet Transform (DWT). KT-Tech also installed Khoros 2.0 on its Sun Sparc IPX workstation in order to locally access the direct manipulation graphical user interface design tool, standardized user interface and documentation, automatic code generation, and interactive configuration management facilities provided by Khoros. In addition, KT-Tech implemented on its Sun Sparc IPX workstation the morphological operators, dilation and erosion, as alternative feature extraction techniques to edge detection operators.

As a part of its contract deliverable with NASA, during the period October 1 - October 31, 1995, KT-Tech completed the development of its DWT-based decomposition algorithm. Utilizing this algorithm, KT-Tech decomposed the Pacific Northwest image into its low-low
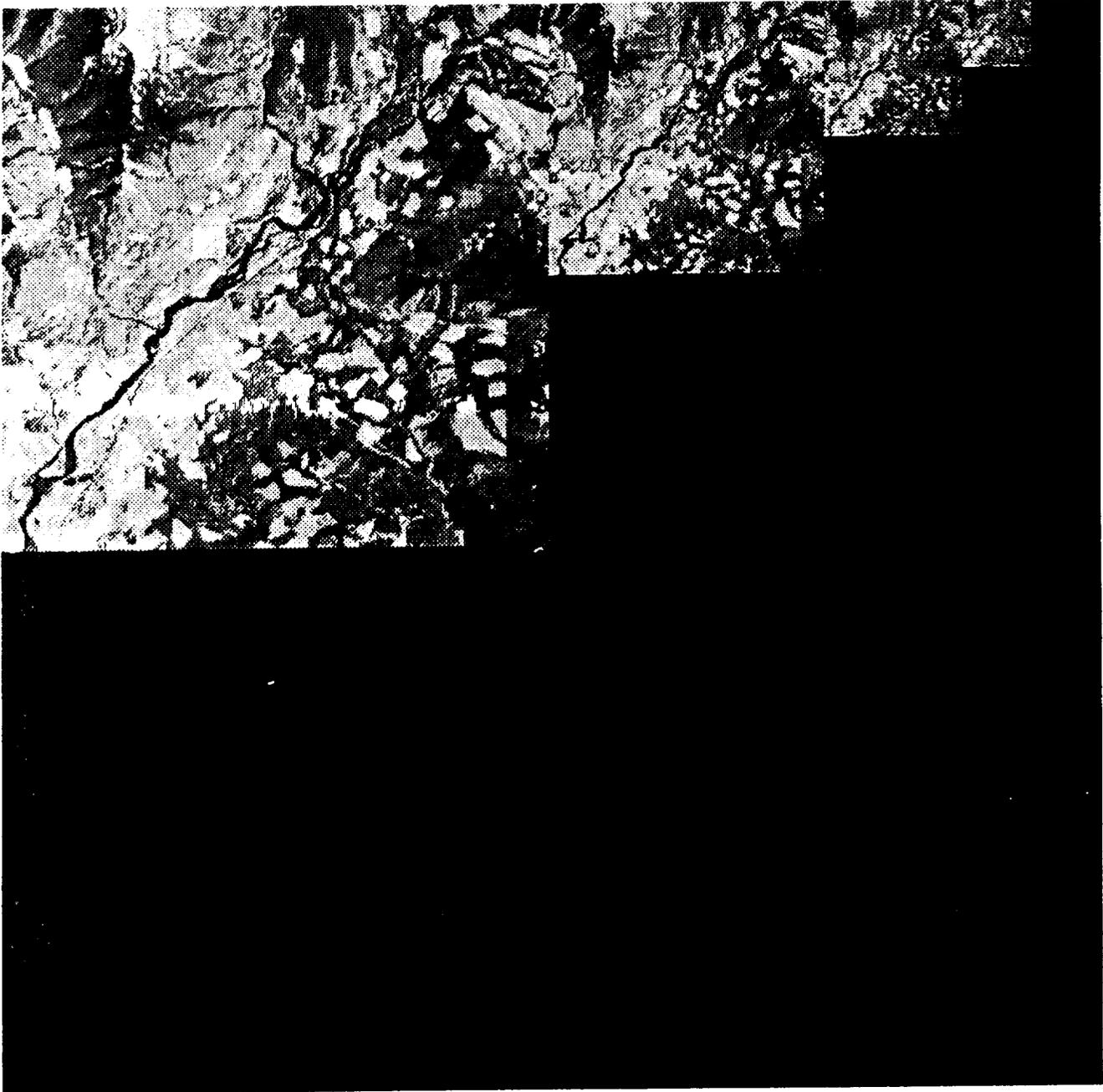
Figure 5. Low-low components of the Pacific Northwest image for the first 4 levels.

(LL), low-high (LH), high-low (HL), and high-high (HH) components for 4 levels. Depending on the application and the type of significant features in the image, one or more of these components contain valuable information on the image that can be employed in the registration process. In addition, KT-Tech continued studying Khoros 2.0 Scientific Software Development Environment.

In Figure 5, the decomposition of the Pacific Northwest image into its LL components for the first 4 levels is illustrated.As a part of its contract deliverable with NASA, during the period November 1 - November 30, 1995, KT-Tech continued investigating the wavelet decomposition technique in the context of registration. After constructing a decomposition algorithm based on the Discrete Wavelet Transform (DWT), KT-Tech applied edge detection algorithms to wavelet decompositions of remote sensing imagery in order to extract the most significant features in the imagery.

Wavelet decomposition of an image results in four components which are called Low-Low (LL), Low-High (LH), High-Low (HL), and High-High (HH). One or more of these components may contain valuable information on the image that can be employed in the registration process depending on the type of significant features in the image. To complement Dr. Jacqueline LeMoigne's work where she utilizes the LH and HL components of the wavelet decomposition of an image, KT-Tech decided to employ the LL component of the wavelet decomposition of remote sensing imagery. KT-Tech applied its Lerner Algebraic Edge Detector (LAED), Sobel edge detector and Prewitt edge detector to the LL component of the wavelet decomposition of remote sensing imagery.

As a part of its contract deliverable with NASA, during the period December 1 - December 31, 1995, KT-Tech constructed a decomposition algorithm based on the Discrete Wavelet Transform (DWT) to obtain the wavelet decomposition of remote sensing imagery resulting in four components which are called Low-Low (LL), Low-High (LH), High-Low (HL), and High-High (HH). For the first four levels, KT-Tech applied edge detection algorithms, KT-

Figure 6. LL components of the Pacific Northwest (LAED/thresholded)

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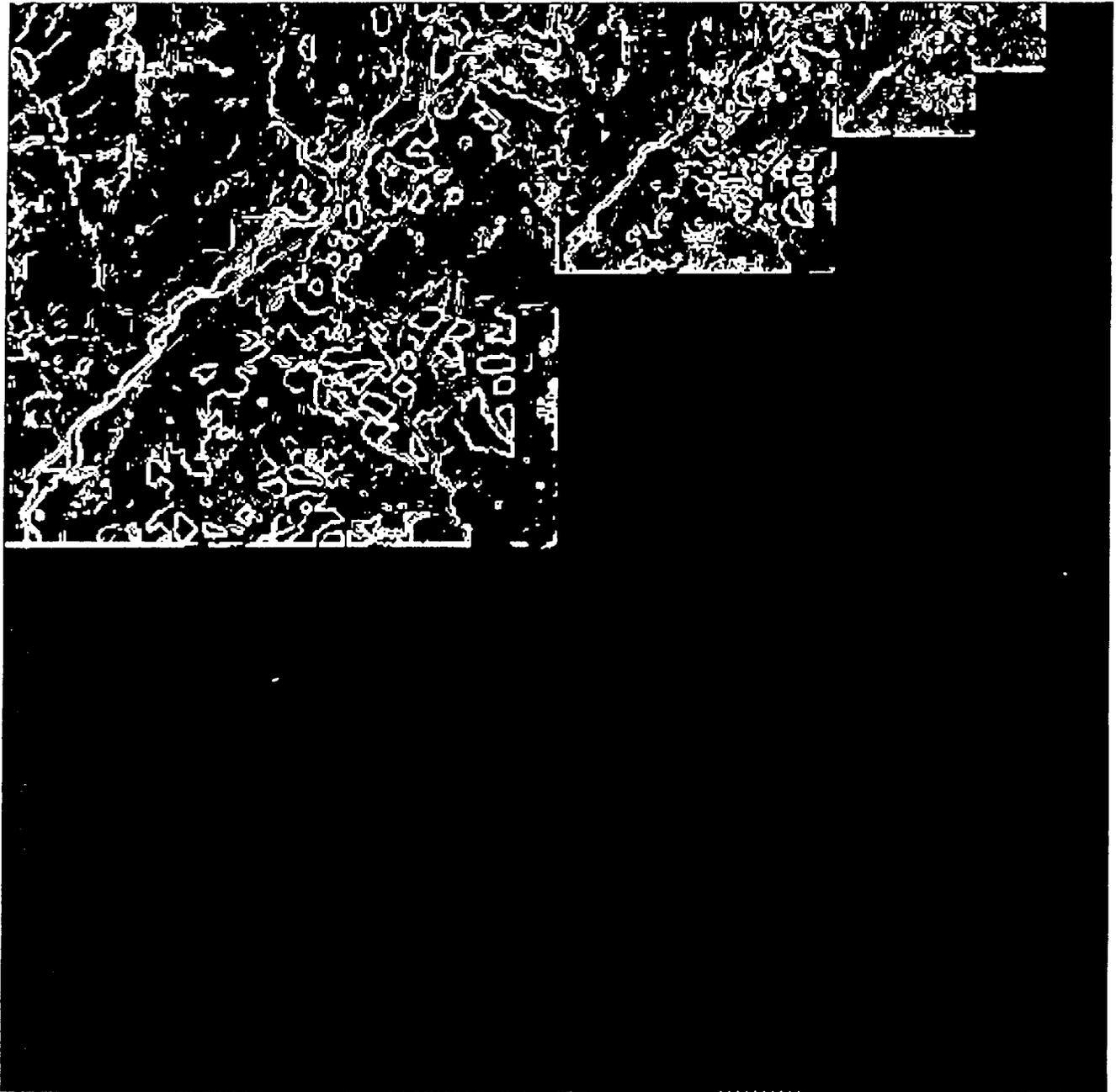
Figure 7. LL components of the Pacific Northwest (Sobel edge detector/thresholded)
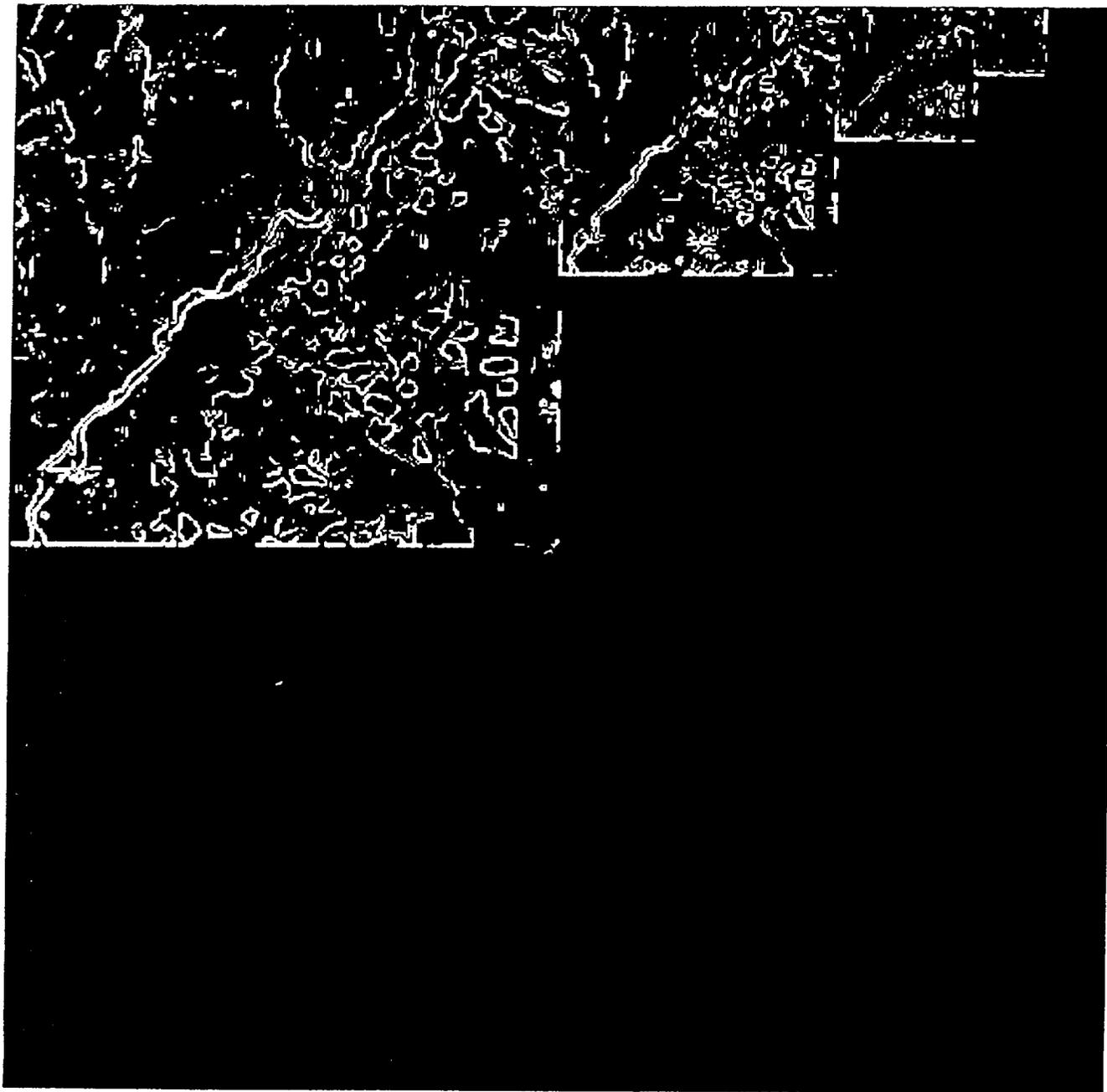
Figure 8. LL components of the Pacific Northwest (Prewitt edge detector/thresholded)

Tech's Lerner Algebraic Edge Detector (LAED), Sobel edge detector and Prewitt edge detector, to the LL components of the wavelet decompositions of remote sensing imagery in order to extract the most significant features in the imagery. In Figures 6-8, the results obtained by applying the LAED, Sobel, and Prewitt edge detectors to the LL components of the original Pacific Northwest image are illustrated.KT-Tech's LEAD, yielded the best results in terms of the extraction of the domain independent features such as boundaries and edges. The application of the LEAD resulted in continuous lines along the edges which are one pixel wide, whereas the Sobel and Prewitt edge detectors yielded disconnected lines which are two or three pixels wide.

As the next step in its investigation, KT-Tech utilized a variation of the registration technique described previously in order to compare the results obtained by the LAED, Sobel, and Prewitt edge detectors. Setting the precision for the angle of rotation θ to $\delta=2°$, KT-Tech started with the lowest resolution LL component (n=4) to determine an approximate value for the angle of rotation, θ_4. The angle of rotation, θ, was then computed in the following manner:

n=4 $\qquad 0° \le \theta_4 \le 90°$

n=3 $\qquad \theta_4 - 16° \le \theta_3 \le \theta_4 + 16°$

n=2 $\qquad \theta_3 - 8° \le \theta_2 \le \theta_3 + 8°$

n=1 $\qquad \theta_2 - 4° \le \theta_1 \le \theta_2 + 4°$, where $\theta_1 = \theta$.

For the Pacific_NW image with LAED, the successive approximation method yielded:

n=4 $\qquad 0° \le \theta \le 90° \quad => \quad \theta = 12°$

n=3 $\qquad -4° \le \theta \le 28° \quad => \quad \theta = 13°$

n=2 $\qquad 5° \le \theta \le 21° \quad => \quad \theta = 15°$

n=1 $\qquad 11° \le \theta \le 19° \quad => \quad \theta = 18°$ (actual $\theta = 18°$)

For the Pacific_NW image with Sobel edge detector, the successive approximation method yielded:

$n=4 \quad 0° \le \theta \le 90° \quad => \quad \theta = 2°$

$n=3 \quad -14° \le \theta \le 18° \quad => \quad \theta = 10°$

$n=2 \quad 2° \le \theta \le 18° \quad => \quad \theta = 10°$

$n=1 \quad 6° \le \theta \le 14° \quad => \quad \theta = 11°$ (actual $\theta = 18°$)

For the Pacific_NW image with Prewitt edge detector, the successive approximation method yielded:

$n=4 \quad 0° \le \theta \le 90° \quad => \quad \theta = 1°$

$n=3 \quad -15° \le \theta \le 17° \quad => \quad \theta = 5°$

$n=2 \quad -3° \le \theta \le 13° \quad => \quad \theta = 7°$

$n=1 \quad 3° \le \theta \le 11° \quad => \quad \theta = 8°$ (actual $\theta = 18°$)

During the period, January 1 - January, 1996, KT-Tech obtained the exclusive-or values for individual angles of rotation and plotted them. The plots peaked at the indicated values for the angle of rotation for each of the edge detectors. However, the peak value was not distinctively different from the other values.

During the same period, KT-Tech composed a research article based on the techniques developed and the results obtained to be submitted to a conference on image processing.

Employing satellite imagery, during the period February 1 - February 29, 1996, KT-Tech continued investigating the linear wavelet decomposition technique in the context of registration. KT-Tech also started looking into the nonlinear wavelet compression technique as an alternative registration technique for multi temporal and/or multi sensor data.

The nonlinear wavelet-based compression differs from the linear wavelet compression in that some of the wavelet coefficients are kept for all levels of the wavelet decomposition in the former whereas all wavelet coefficients are kept for up to a predetermined level of the wavelet decomposition in the latter. Consequently, the nonlinear wavelet compression produces higher compression ratios and eliminates more redundancy from the uncompressed image. This feature seems to be quite useful in the context of registration since the use of only the most significant features (control points) reduces the computation time and the number of false peaks in the pixel histogram.

During the same period, KT-Tech also employed cross-correlation as an alternative similarity metric in addition to the exclusive-or operation in its linear wavelet decomposition based registration algorithm since the exclusive-or operation did not produce very distinctive peaks indicating the actual angle of rotation.

As a part of its contract deliverable with NASA, during the period March 1 - March 31, 1996, KT-Tech started refining it linear wavelet decomposition based registration technique. KT-Tech also continued studying the nonlinear wavelet compression technique in the context of registration.

KT-Tech had been investigating various image processing techniques to solve the potential problems that may be introduced due to the fact that the similarity metrics employed for a given range of angles produce a pixel histogram that does not exhibit any sharp peaks to indicate the exact angle of rotation. In its investigation, KT-Tech determined that certain morphological operators would extract the significant features in the input and reference images that might enhance the performance of the registration process by improving the computing speed and producing a sharper peak in the pixel histogram.

Based on its thorough research on morphological image processing, KT-Tech concluded that among the morphological operations based on erosion and dilation, opening and closing were the most well-suited ones for preprocessing images for the purposes of registration. Thus

KT-Tech implemented the opening and closing morphological operations on its Sun Sparc IPX workstation.

During the same period, KT-Tech also continued investigating the nonlinear wavelet-based compression in the context of registration. KT-Tech studied research articles written in this area to find a quantitative measure which would describe the complexity in the structure of the images to be registered. This quantitative measure could be utilized to develop a thresholding strategy that would retain only certain wavelet coefficients producing an optimal compression that would vary with the complexity of the image.

During the period April 1 - April 30, 1996, KT-Tech utilized the opening and closing morphological operations as an intermediate step following the linear wavelet decomposition and prior to LEAD. The preliminary results indicated that the number of redundant features in the images preprocessed by the opening and closing operations were reduced significantly and only the most significant features are retained.

Figures 9 and 10 show the resulting images when the Pacific Northwest image is preprocessed utilizing the closing and the opening morphological operators prior to the application of the LAED, respectively.

During the same period, KT-Tech started taking the preliminary steps in incorporating the linear wavelet-based decomposition algorithm, the opening and closing morphological operations and the LAED into KT-Tech's algorithm for registration by successive approximation.

In addition to its wavelet-based registration algorithm, KT-Tech was also assigned another method that uses a wavelet-based point feature extraction algorithm to select distinct and consistent point features across images. This method incorporates local statistical information of the image intensity to locate point features in multi resolution contour maps generated using the wavelet transform.

Figure 9. The original Pacific Northwest image processed by the closing morphological operator and the LAED.
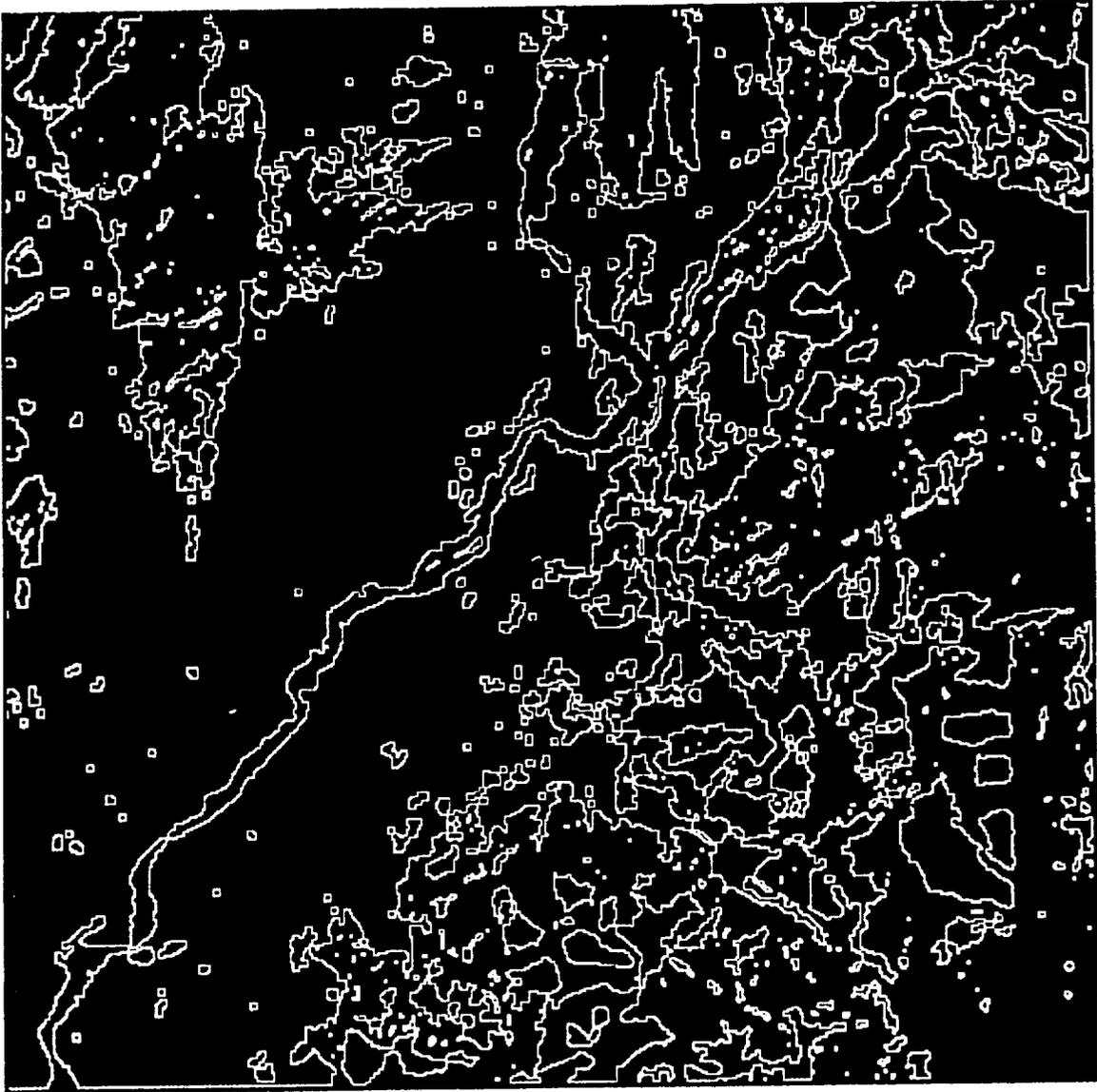
Figure 10. The original Pacific Northwest image processed by the opening morphological operator and the LAED.

KT-Tech's performanceand the results it obtained during the first year of the contract can be summarized as follows:

Automated registration of images is a nontrivial problem. Registration can be viewed as a combination of four components: i) feature space, ii) search space, iii) search strategy, and iv) similarity metric. The feature space, i.e., the set of characteristics or ground control points that are to be inferred from the input and reference images to perform registration, is one of the most important components of registration. These ground control points must contain the most significant information on the images. Hence, by removing the redundancy present in the images while preserving only the most relevant information, registration process becomes computationally less intensive.

KT-Tech started to utilize morphological and algebraic image operators for extracting domain-independent and shape-related rather than brightness-related features, such as boundary extraction and delineation, as well as recent discoveries (wavelet techniques) in image processing to develop fast algorithms and registration of digitized images. Hence, as a preprocessing step, KT-Tech started to employ robust feature extraction techniques for obtaining well-defined ground control points.

KT-Tech's investigation illustrated that the performances of Sobel and Prewitt edge detectors were very similar. The LEAD, however, yielded the best results in terms of the extraction of the domain independent features such as boundaries and edges. The application of the LEAD resulted in continuous lines along the edges which are one pixel wide, whereas the Sobel and Prewitt edge detectors yielded disconnected lines which are two or three pixels wide.

For registration, it is desirable to have continuity along the edges, as well as lines that are as narrow as possible. Hence, it was anticipated that the LAED would perform within a registration scheme better than the other conventional edge detectors, Sobel and Prewitt.

The next step in KT-Tech's investigation was the comparison of the LAED, Sobel, and Prewitt edge detectors within the registration scheme described in the previous section. A reference Pacific Northwest image and an input image that was the rotated version of the reference image by a given angle, $\theta=18°$, were preprocessed by the LAED, Sobel, and Prewitt edge detectors to extract the most significant information in the images.

KT-Tech then applied the registration scheme described in the previous section to the preprocessed reference and input images. The performance of the LAED was superior to that of the Sobel and Prewitt edge detectors.

KT-Tech's investigation illustrated that the registration of two preprocessed images in the spatial domain is a very difficult problem because of their sizes. The registration of two 512 x 512 images was computationally very intensive although the images were preprocessed to remove the redundancy and to preserve only the most significant information. Hence, the computations that needed to be performed for registration were very time consuming.

Since the application of the registration scheme to the original image and its rotated version did not yield satisfactory results, as the next step, KT-Tech started investigating multiresolution approaches, in particular, the wavelet decomposition technique.

The next step in KT-Tech's investigation was the application of the LAED, Sobel, and Prewitt edge detectors to wavelet decompositions of the reference and input images. KT-Tech showed that the LAED performes within this registration scheme better than the other conventional edge detectors, Sobel and Prewitt, since it produces continues lines that are one pixel wide along the edges and it preserves the most significant information on the image. LEAD was able to indicate the actual angle of rotation, whereas the results obtained by Sobel and Prewitt edge detectors were unacceptable.

Registration of two images by the successive approximation method based on the wavelet decomposition method was very time efficient and computationally less intensive than the

registration of the two images in the spatial domain. However, the use of the exclusive-or operation as the similarity metric did not produce very distinctive peaks.

The smoothness of the pixel histogram was due to the fact that at any given resolution level, the number of pixels corresponding to features in the images, i.e., the pixels that were non-zero, was relatively high. In addition, the input and the reference image were thresholded at each resolution level resulting in pixel values that were either 0 or 255. As a consequence, the cross-correlation as well as the exclusive-or values tended to be similar for any given angle since the values of the pixels at the corresponding locations of the reference and the input images could be the same even if those pixels did not represent the same location in both images.

Therefore, KT-Tech started investigating image processing methods that would reduce the redundancy in the images while preserving only the most significant features. Based on its research, KT-Tech concluded that the morphological operations opening and closing would accomplish this task.

The opening operation is obtained by an erosion followed by a dilation. The closing operation is the dual of the opening operation and is obtained by a dilation followed by an erosion. Erosion is a shrinking operation, whereas dilation is an expansion operation. The two most important properties of erosion and dilation operations are that they are translation invariant, i.e., a translation in the object causes the same shift in the result, and they are not inverses of each other. Thus, opening and closing operations derived from erosion and dilation operations could be utilized in a way which would improve the performance of KT-Tech's linear wavelet decomposition based registration algorithm.

The opening operation smoothes contours, suppresses small islands and sharp caps of the input image. The closing blocks up very narrow channels and thin lakes. Hence, they are perfect candidates for removal of redundancy from the input and reference images.

Contract Performance and Analysis of the Results Obtained During Year 2

As a part of its contract deliverable with NASA, during the period May 1 - May 31, 1996, KT-Tech integrated the opening and closing algorithms that had been implemented on its Sun Sparc Workstation into its registration algorithm. KT-Tech showed that the opening and closing algorithms help improve the performance of the image preprocessing step by removing redundancy from the input and reference images while retaining only the most significant features.

KT-Tech also submitted an abstract for a paper entitled "Registration of satellite imagery utilizing the low-low components of the wavelet transform" to SPIE's Applied Imagery Pattern Recognition '96 Workshop which would be held in "Cosmos Club," Washington, D.C., in October 1996.

During the same period, KT-Tech continued studying Khoros 2.0 Scientific Software Development Environment since the registration methods developed by the members of the registration group headed by Jacqueline Le Moigne would be integrated to obtain a Khoros-based toolbox of automatic geo-registration methods.

As a part of its contract deliverable with NASA, during the period June 1 - June 30, 1996, KT-Tech started studying a registration technique, proposed by Li and Zhou, utilizing wavelet transform and edges. This technique can be applied to multi-sensor data with discrepancy in their gray scale characteristics.

This wavelet-based point feature extraction method selects distinct and consistent point features across images. This algorithm overcomes the difficulty of registering multi-sensor data, such as visual/IR imagery, particularly due to the discrepancy in their gray-scale characteristics. It utilizes the local statistical information of the image intensity to locate point features in multi-resolution contour maps generated using the wavelet transform.

During the same period, KT-Tech volunteered to present a poster entitled "Multi-resolution Geo-registration of Remote Sensing Imagery Employing the Wavelet Transform" based on its image registration work in Jim Tilton's Atrium Teas and Posters Sessions. The poster was displayed in the south-west atrium of Building 28 on June 13, 1996. KT-Tech personnel was available at that location from 3:00 pm to 4:00 pm to answer the questions by the guests. The poster received a positive reaction from the guests.

During this period, KT-Tech started debugging its automated registration algorithm in order to ensure a problem-free operation after its incorporation to the automated image registration toolbox that is being developed under the direction of Dr. Le Moigne. KT-Tech discussed with Dr. Le Moigne and Wei Xia possible Graphical User Interface/Window Layouts appropriate for KT-Tech's registration algorithm.

In addition, KT-Tech started planning its input to a paper that will be written by the members of the registration group based on the comparison of methods developed and the results obtained.

As a part of its contract deliverable with NASA, during the period July 1 - July 31, 1996, KT-Tech continued enhancing and debugging its registration algorithm.

KT-Tech implemented an adaptive thresholding method that utilizes image-specific threshold values. This algorithm sets a predetermined number, e.g. 15 %, of the pixels having the highest gray-level value to 255 and the remaining pixels to 0. This method ensures that the number of pixels that are non-zero remains constant for all edge detection methods including the LAED and Sobel edge detector. As a consequence, comparison of the performance of edge detection methods becomes very convenient.

KT-Tech's LAED and other image processing algorithms had been implemented on KT-Tech's local Sun Workstation employing X-Windows Widgets. KT-Tech had been rewriting the

LAED and its other image processing algorithms in order to obtain their platform- and compiler-independent versions.

In addition, KT-Tech learned that its image registration paper had been accepted to SPIE's Applied Imagery Pattern Recognition '96 Workshop.

As a part of its contract deliverable with NASA, during the period August 1 - August 30, 1996, KT-Tech completed implementing its image registration algorithm based on wavelet decomposition and successive approximation method.

During this period, KT-Tech interfaced its existing algorithms and started debugging its automated registration algorithm in order to ensure a problem-free operation after the integration into the registration toolkit. However, a problem arose during implementation: the integrated program did not perform satisfactorily, although the programs individually ran successfully.

During this period, KT-Tech discussed with Dr. Le Moigne and Wei Xia an appropriate Khoros-based Graphical User Interface (GUI) with four windows for KT-Tech's registration algorithm: i) the input image, ii) the reference image, iii) a text window for messages, e.g., current level, current x-size and y-size, etc., and iv) the output image. Since KT-Tech's algorithm existed as a single C program with subroutines, the only changes that would have to performed in order to obtain the Khoros version would be the ones pertaining to data input and output.

As a part of its contract deliverable with NASA, during the period September 1 - September 31, 1996, KT-Tech completed the implementation and debugging of its image registration algorithm based on wavelet decomposition and successive approximation method. By the middle of this period, KT-Tech completed fixing the bugs in the program.

KT-Tech then delivered the integrated program to NASA by the middle of September. Dr. Le Moigne installed the programs, header files, and libraries to the anonymous ftp site on

"cesdis". KT-Tech recompiled its programs, and tested them. KT-Tech also uploaded its registration code to its "nibbles" account and recompiled them.

As a part of its contract deliverable with NASA, during the period October 1 - October 31, 1996, KT-Tech started testing its registration algorithm utilizing some of the test images from Dr. Le Moigne's anonymous ftp site including the Pacific_Northwest, Hannah_with_Hat, and Grid images. KT-Tech's algorithm successfully registered those images.

At the beginning of this period, Wei Xia started porting KT-Tech's registration algorithm to the Khoros environment.

Also at the beginning of this period, KT-Tech started working on the presentation of its paper in the SPIE/AIPR Conference on October 16, 1996 and prepared the viewgraphs for the presentation. KT-Tech presented its SPIE/AIPR paper in Bob Cromp's session entitled "Image Mining" and received a positive feedback from the audience.

During this period, KT-Tech prepared a document briefly explaining its registration algorithm which would be incorporated into a larger document containing the algorithms developed by the other members of the Registration Group and would be utilized when applying for NASA as well as outside funding.

During this period, KT-Tech also started working on a paper on image registration utilizing the non-linear wavelet transform which would be presented at the SPIE Conference on Wavelets in Orlando, Florida. KT-Tech submitted an abstract of the paper to Dr. Harold Szu who would chair the session.

As a part of its contract deliverable with NASA, during the period November 1 - November 30, 1996, KT-Tech continued working on its registration paper that would be presented during SPIE's Conference on Wavelets in Orlando, Florida, in April 1997. This paper contained KT-Tech's initial research and results in the area of image registration utilizing nonlinear wavelet transformation.

During this period, KT-Tech also talked several times with Wei Xia to answer her questions regarding KT-Tech's registration algorithm which is based on the linear wavelet transform. She had been tasked by Dr. Le Moigne to port KT-Tech's registration algorithm as well as the algorithms developed by other members of the Registration Group to the Khoros environment.

As a part of its contract deliverable with NASA, during the period December 1 - December 31, 1997, KT-Tech continued working on its registration paper that would be presented during SPIE's Conference on Wavelets in Orlando, Florida, in April 1997.

Research related to the SPIE paper produced concrete and promising results on image registration using nonlinear wavelet compression. Tasks were delegated for documenting the experiments, writing up sections of the paper, and compiling the paper. The first draft of the paper was completed December 15, 1996.

In addition to its continued work on the SPIE paper, KT-Tech continued supporting Wei Xia in her effort to port to the Khoros environment KT-Tech's registration algorithm. KT-Tech assisted Wei Xia in the problems that she encountered during the code porting process by explaining in detail components of its algorithm. KT-Tech discussed with Wei Xia, in particular, extraction of the control points utilizing the linear wavelet decomposition and the Lerner Algebraic Edge Detector (LAED), and registration of the input and reference images by successive approximation utilizing the control points extracted.

As a part of its contract deliverable with NASA, during the period January 1 - January 31, 1997, KT-Tech completed its SPIE paper on image registration employing the nonlinear wavelet transform. The final version of the paper was sent to SPIE by January 27, 1997.

During this period, KT-Tech started researching methods that would compute the complexity index of the images to be registered in order to determine the optimal registration method.

KT-Tech also started researching the significance of the choice of error metric which would allow KT-Tech to quantify a criteria for comparing the effectiveness of different ways of compressing an image for the purpose of registration.

In the current stage of its research, KT-Tech's search space was limited to rotation. Dr. LeMoigne asked KT-Tech to add translation and scale change to the search space during the upcoming periods.

As a part of its contract deliverable with NASA, during the period February 1 - February 28, 1997, KT-Tech produced and delivered to Wei Xia a document describing KT-Tech's registration algorithm which is based upon the linear wavelet transform. This document would be included in the help section of the registration toolkit and in the final documentation.

During this period, KT-Tech also started revising the code of its algorithm. In the original program, all input and reference arrays as well as the arrays that were used for intermediate computations were defined as fixed-sized arrays. The size of the arrays could be set to a large value. However, in order to change this value, the size had to be redefined and the program needed to be recompiled. KT-Tech began working on the program to change the declared arrays to pointers to eliminate the need for recompiling the program for different sized.

During this period, KT-Tech also started making contacts in the West Coast with Universities as potential RVC sites.

During the period March 1 - March 31, 1997, KT-Tech continued making contacts on the West Coast with Universities as potential RVC sites. KT-Tech detected three institutions in North Central California whose activities suggested an RVC affiliation would be advantageous, or whose activities were of a de-facto RVC nature: University of Nevada, Reno's Western Regional Climatic Data Center, University of California, Santa Cruz's Reinas Project, and University of California, Davis' Center for Spatial Technologies and Remote Sensing (CSTARS).

CSTARS and its PI, Dr. Susan Ustin, was the one who responded most actively. Effort was directed towards identifying along with this group other centers, and departments at UC Davis which could complement the facilities and research backbone of CSTARS, and to identify funding sources and a client base (Federal, State agencies, local commercial clients) which could serve as the basis for endorsement by Deans of the University, leading to an MOU by the Chancellor. KT-Tech identified CSTARS and elements of the Department of Land, Air, and Water Resources Management Department as the backbone of the research/applications activity, elements of Computer Science who could provide database management expertise, and a center for image processing and integrated computing (CIPIC) on campus which was interested in participating in the information fusing and visualization tasks associated with the research effort. Progress was also made in identifying possible funding sources and clients. A preliminary draft of the status report of this effort was e-mailed to William Campbell on March 20, and discussed with him at the meeting March 25.

During this period, KT-Tech also continued conducting research on geo-registration. KT-Tech changed the declared arrays to pointers eliminating the need for recompiling the program for different sized images.

In addition, during this period, KT-Tech started working on the RVC code port from HP UNIX environment. KT-Tech started studying the system and its requirements.

KT-Tech downloaded and installed on its SUN workstation at Code 935 TCL 7.6 and TK 4.2 and made the necessary changes to ensure that they ran without any problems on that platform. KT-Tech also started studying Khoros since some of the work developed by Samir Chettri utilized Khoros.

KT-Tech then started studying Samir Chettri's Khoros and George Fekete's TCL/TK codes. To be able to run George Fekete's interface, KT-Tech installed CVS 1.9, RVC 5.7, and Diffutil on its SUN workstation.

During the period April 1 - April 30, 1997, the results of KT-Tech's registration work was presented in a paper at the SPIE AeroSense97 conference, "Using Wavelet Compression to Enhance Registration". The paper received a very positive reaction from the audience.

During this period, KT-Tech continued activity at UCDavis on nonlinear wavelet compression and registration with J. Pinzon. KT-Tech initiated the modules for registration by moments and for registration by control points, examining how they interface.

KT-Tech also outlined with J. Pinzon and R. DeVore validation activity for the nonlinear wavelet registration team's contribution to the registrations group's response to MPTE NRA97-07. KT-Tech took lead in this effort by composing a letter of intent and first draft of proposal.

During this period, KT-Tech continued interactions with centers/personnel at UCDavis on forging an RVC

KT-Tech also continued its work in the area of code port. KT-Tech delivered to NASA an RVC Software Module Improvement Report. This report is not included in this final report due to its size.

During this period, KT-Tech also completed porting of the "Algorithm" part of the RVC system and is in the process of porting the "Query Interface".

KT-Tech's performance and the results it obtained during the second year of the contract can be summarized as follows:

KT-Tech had been developing a registration by successive approximation algorithm utilizing the LL components of the linear wavelet decomposition of the reference and input images preprocessed by the LAED and the Sobel edge detector. KT-Tech successfully registered remote sensing as well as facial images utilizing its registration technique combined with the LAED. However, after plotting the pixel histograms obtained during the registration by successive approximation process, KT-Tech has realized the lack of a very sharp peak in the pixel histogram distinctly indicating the exact angle of rotation.

The smoothness of the pixel histogram was due to the fact that at any given resolution level, the number of pixels corresponding to features in the images, i.e., the pixels that were non-zero, was relatively high. In addition, the input and the reference image are thresholded at each resolution level resulting in pixel values that are either 0 or 255. As a consequence, the cross-correlation as well as the exclusive-or values tend to be similar for any given angle since the values of the pixels at the corresponding locations of the reference and the input images can be the same even if those pixels do not represent the same location in both images.

To solve this problem, KT-Tech added a new thresholding technique as well as a new similarity metric to its program to enhance its performance. The new thresholding technique maintains the gray-level values of a predetermined number, e.g. 15 %, of the pixels and sets the gray-level values of the remaining pixels to 0. This method ensures that the number of pixels that are non-zero remains constant for all edge detection methods including the LAED and Sobel edge detector. It also minimizes the effect of the erroneous matching of pixels as explained previously. As the similarity metric, KT-Tech started utilizing the mean square error (MSE) between the gray level values of the pixels of the input and the reference image since the MSE is a much more accurate measure of similarity then the exclusive-or operation.

As a consequence of the emerging SPIE paper and the promising results obtained, KT-Tech decided to concentrate its registration research on using nonlinear wavelet methods. KT-Tech began work on outlining a research program to guide investigations in this direction. Initial results KT-Tech obtained indicated that very high nonlinear wavelet-based compression of the input and reference images could be utilized to obtain the control points that could then be used to register the images. As an added advantage, employment of nonlinear wavelet compression would dramatically reduce the computational intensity of the registration process.

KT-Tech decided to investigate, during the upcoming periods, how to optimally extract control points for registration using highly compressed versions of the input and reference images. KT-Tech deceided also to conduct research on how to use highly compressed versions of the input and reference images to register them when they differ first by a pure rotation, then by a pure translation, and then by a rigid transformation (translation superimposed upon a rotation).

KT-Tech also decided to investigate in depth the methodology for isolating control points by compression of the reference and input images, as well as the statistical confidence the registration produces as a function of number of control points, the confidence with which the control points isolated in the reference and input image were in fact true pairs.

Previously, KT-Tech's registration efforts were directed towards extending the algorithm for registering highly compressed images to the class of rigid, global transformation, from purely rotational transformation. The results of this work were presented in a paper to SPIE in April and the feedback from the audience suggested that KT-Tech's research was considered very promising. Work was also initiated on exploring registering the highly compressed images using less precise, but more rapid approaches: using moments derived from the compressed reference and input images.

In addition, KT-Tech revised its linear wavelet-based registration algorithm to utilize pointers instead of fixed sized arrays. In the revised program, there were no predefined arrays and the need for recompiling the program for different sized images was eliminated.

KT-Tech's code porting activity was also in progress. KT-Tech completed porting of the first module of the RVC system and was in the process of porting the second one. The remaining two would be ported as soon as the necessary software tools became available.

Contract Performance and Analysis of the Results Obtained During Year 3

During the nineth quarterly period, May 1 - July 30, 1997, KT-Tech, Incorporated continued broadened or initiated activities for Code 935 in four areas. In the area of image geo-registration it continued one and initiated a second contribution to the registration toolbox being developed for the RVC's. In the area of spectral analysis, KT-Tech initiated a multi-scale approach to feature extraction from spatially distributed spectral data. KT-Tech continued its activity to foster the establishment of an RVC at UC Davis. Finally, KT-Tech continued and enlarged its activity to port the RVC database and management system to a Sun/Unix environment.

I. Registration Activity

At the end of the eighth quarterly period, KT-Tech was engaged in completing the development of a registration algorithm based upon linear wavelet decomposition techniques for the registration working group directed by Dr. J. LeMoigne. KT-Tech opened a discussion with Code 935 and Dr. LeMoigne to broaden this registration activity to include the development and implementation a computationally rapid way to register images based upon nonlinear wavelet compression and singular valued decomposition techniques. During the seventh quarter KT-Tech had established the feasibility of such a registration algorithm based upon nonlinear wavelet compression, and had presented the results in a paper at the AeroSense97 conference in the eighth quarter.

Registration using nonlinear wavelet compression and SVD tools.

During the nineth quarter, KT-Tech established the viability of rapidly registering the nonlinearly compressed images using singular valued decomposition (SVD) techniques. Working with J. Pinzon (UC Davis) and J. Pierce, KT-Tech negotiated with Bill Campbell and J. LeMoigne a scope of work and timeline to implement this second registration algorithm for the

registration toolbox. This registration activity was to involve J. Pinzon and J. Pierce, initiate July 1 and complete September 30.

By July 15, the main modules of the nonlinear wavelet and SVD-based registration algorithm were completed and functioning as MatLab code, utilizing the WaveLab library. The first stage of the algorithm compresses the reference and input images, extracting hot pixels which manifest features significant to each image. A stability feedback loop allows the SVD computations performed at the second stage to refine the compression, so as to maximize the probability that the ensemble of hot pixels in both images manifest features which match under registration; hence, are viable control points. The information from the SVD stage then drives the third stage, which produces the registration. A feedback loop in that stage refines the accuracy of the registration.

MatLab was chosen as the developmental environment, because the WaveLab library available to it closely approximated the library availiable in the emerging toolbox, because of the ease with which the code's computational and graphic elements could develop, because of the ease with which the MatLab code translates into C code, the basis for the toolbox algorithms, and because of the ease with which the graphic elements used in the MatLab code would translate into the Khoros environment, the graphics enviornment for the toolbox.

Also by July 15, J. Pinzon and J. Pierce had subjected the algorithm to three of the validation tests set forth by J. LeMoigne and the registration working group for all registration algorithms. The results demonstrated to KT-Tech the functionality of the algorithm and isolated some elements to refine in order to improve the code's efficiency, stability and robustness.

During the week July 21-July 25, 1997, J. Pinzon visited GSFC under the aegis of CESDIS and Code 935, through KT-Tech. His principal activity was to demonstrate the viability of the algorithm to J. LeMoigne, to work with Wei Xia to demonstrate the functionality of the algorithm as C-code, to establish how to interface the algorithm as seamlessly as possible with

the Khoros graphics environment, and to determine how to incorporate the modules of the algorithm as effectively as possible into the registration toolbox.

The July visit established the functionality of the algorithm. It also revealed ways to significantly improve the robustness and efficiency of the algorithm, established the importance of adequate documentation for the code, and underscored the need for setting forth firmly the mathematical foundation upon which the algorithm is based. In the latter part of July 1997, J. Pinzon and J. Pierce began to address these points. Improvements in the code would produce refinements of the compression stability and the registration refinement feedback loops, and the establishment of a loop to assess intrinsic geometric symmetry in the reference and input images.

In June 1997 an abstract for the paper "Image registration by nonlinear wavelet compression and singular value decomposition" was submitted to the CESDIS/IEEE Registration Workshop at GSFC in November 1997. The paper describes the algorithm, its mathematical basis, its implementation, and its performance against the validation tests. In July 1997 the paper was accepted for presentation.

Registration using the Low-Low component of a linear wavelet decomposition

During the nineth quarter KT-Tech, through E. Kaymaz, continued its work developing an algorithm for geo-registration using the Low-Low component of a linear wavelet decomposition of reference and input images. By the end of the eighth quarter KT-Tech had implemented and refined a version of the algorithm which registered images differing by a global two-dimensional rotation. In June 1997, KT-Tech broadened the program into one whose search space consisted of rotations and two-dimensional translations.

The algorithm involves three steps. In the first step it produces the wavelet decomposition of the reference and input images to be registered. In the second step it extracts domain independent features to be used as the control points from the low-low components of the wavelet decompositions of the reference and input images. The Lerner Algebraic Edge Detector

(LAED) is employed to enhance the extraction process. In the third step the program utilizes the maxima of the low-low wavelet coefficients preprocessed by the LAED and a mean square error (mse) based similarity metric to compute the transformation function. The search space consists of two dimensional rotations and shifts in the x- and y-directions. Details of the search strategy are presented in Appendix A.2. The strategy can be summarized as:

Step 1: Perform wavelet decomposition on the reference and input images up to level N to obtain the LL components of the decomposition. Keep all wavelet coefficients up to level n=N.

Step 2: Apply the edge detector to all LL images obtained from the reference and input images up to level n=N to extract the most significant edge information.

Step 3: Starting with the highest level of decomposition, find the best approximation to the angle of rotation, and x- and y-translations iteratively for each level with increasing accuracy employing the search strategy described below.

Validation of the algorithm and the assessment of its stability under rigid body transformation commenced in July. KT-Tech found it could lock up the algorithm with some validation tests. KT-Tech then engaged in isolating those elements in the code which precipitated the obstruction, and assessing if the obstacle was fundamental to the design of the algorithm, or an error in the code implementing it.

II. Spectral Analysis Activity

At the beginning of the nineth quarter KT-Tech, through J. Pierce, began to discuss with J. Pinzon and the CSTARS laboratory at UC Davis the development of an approach to spectral analysis which integrated the multi-resolutional capabilities of wavelets in the spatial domain with the multi-scale approach to feature extraction from spectra developed by Dr. S. Ustin at UC Davis, director of the CSTARS laboratory, and others. It appeared to KT-Tech that if such an approach could be brought from the research into the developmental stage, it would serve as the

basis for data products for RVC's at UC Davis, GSFC, and other locations. In May 1997, KT-Tech, through J. Pierce, began discussions with W. Campbell, J. LeMoigne and T. Gaultierri, GSFC, about the possibility of how such work might interface with spectral feature extraction activity in Code 935, and with S. Ustin and J Pinzon, UC Davis, about the relevance and viability of engaging in such activity at CSTARS. By the end of May 1997 it was mutually agreed that, in addition to developing and putting the nonlinear registration algorithm in place, J. Pinzon would present a seminar on the topic during his second visit to GSFC in August 1997, and would broaden discussions with J. LeMoigne, T. Gaultierri, and possibly P. Cheeseman at ARC, to produce avenues of activity relevant to the Code 935 and the RVC effort. If the proposed activities proved acceptable, they would be considered for start up in October 1997.

During his first visit to GSFC in July 1997, J. Pinzon spoke at length with T. Gaultierri, and J. LeMoigne about activities at Code 935 in spectral feature extraction, and presented informally the method of multi-scale spectral feature extraction, Hierarchical Foreground Background Analysis (HFBA) currently being used to great advantage at CSTARS.

Upon his return to UC Davis at the end of July 1997, and with the assistance of J. Pierce, J. Pinzon began to develop an abstract for three avenues of activity for integrating wavelet decomposition methods in the spatial domain with the HFBA decomposition in the spectral domain for extracting and validating both supervised and unsupervised classification of spatially distributed spectral data.

III. RVC Code Porting Activity

During the eighth quarter KT-Tech had begun work on the RVC code porting from the HP enviornment to the SUN UNIX environment. Although the activity focused primarily on the restructuring of code for individual modules, it became apparent early on that KT-Tech had to comprehend the system design and overall logic of the RVC system, if the programs it ported were to contribute to the ultimate goal of a modularized system, robust in its design and application, and capable of porting to numerous environments. Towards that end, KT-Tech,

through R. Liao, contributed the "RVC Software Module Improvement Report" in the eighth quarter, a report design which specifies the porting activity in the context of the major modules of the RVC system.

To support the porting activity KT-Tech received in May 1997 access to a SUN Ultra 1 machine (fusion.gsfc.nasa.gov) in Code 935. During May and June, KT-Tech, through R. Liao, augmented hardware on the computer, replaced the operating system with Solaris 2.5.1, and installed SUN Ultra Allegro Common LISP for the Solaris operating system.

To support the production of a code applicable to a library of environments (HP, UNIX, DOS), it quickly became clear in the eighth quarter that "inlining" calls to functions specific to the UNIX environment were counterproductive. Consequently, in the nineth quarter, KT-Tech, through R. Liao, developed and introduced the routine "platform.c", which provided a wrapping function to all platform dependent function calls. It was significant, because introducing this routine and replacing "inline" code with calls to it modularized the environmentally specific function calls. Whenever the RVC is cast into a new operating environment in the future, one need only modify "platform.c", rather than alter all "inline" calls for environmentally specific functions. The routine "platform.c" is modified as porting progresses through all elements of the RVC.

Porting the emerging versions of the RVC to a SUN UNIX environment involves the modification of programs in all the major modules: user interface, ingest, the planner/scheduler/dispatcher (PSD) and its curator submodule, and the database module. After configuring the SUN Ultra 1, KT-Tech, through R. Liao, proceeded to port onto it and into the UNIX environment the current and emerging versions of the various modules in the manner described below. These activities occurred during the months of June and July 1997, and they recurred as modifications or revisions in the emerging RVC code dictated.

User Interface Module

To establish the user interface module in the UNIX environment, KT-Tech, through R. Liao, ported onto the SUN Ultra 1 the RVC Interface program, and the package for Tcl7.6/Tk4.2, modified by G. Fekete to function with the RVC Interface program. Tcl/Tk is the means by which the user interacts over the interface with the other elements of the RVC. In the course of this activity, KT Tech ported to the UNIX environment a utility package, "Util" into the c-shell. This utility is used in installing the RVC.

Ingest Module

In support of the Ingest module, KT-Tech, through R. Liao, ported the program "Ingest" and its modifications to the SUN Ultra 1 and UNIX environment.

Database Module

In June 1997, KT-Tech received version 4.0 of ObjectStore, the database engine for the RVC. Through R. Liao, KT-Tech completed the installation of ObjectStore on the SUN Ultra 1. In July 1997, KT-Tech ported the object-oriented database interface program,"Odi", to the SUN UNIX environment. This program builds the RVC database into the ObjectStore medium.

Planner/Scheduler/Dispatcher (PSD) Module

With the installation of Allegro C. Lisp and ObjectStore 4.0, KT-Tech was able to begin porting the latest version of the PSD program. In June and July 1997, KT-Tech, through R. Lan, ported it and its modifications to the SUN Ultra 1 and UNIX environment. KT-Tech also ported a "Tcl-geewix" program running on Tcl7.4/Tk4.0. This program assists the Planner in the construction of the information for the Gant charts used in the time management.

IV. RVC Activity

By the end of the eighth quarter, in consultation with W. Campbell, Code 935, and with the assistance of J. Pierce, KT-Tech had focused attention on sheperding the formation of an RVC based at University of California, Davis, centered at the Center for Spatial Technologies

and Remote Sensing (CSTARS). Progress had been made on identifying departments, groups and centers at UC Davis and in the UC system which could complement the facilities and research backbone of CSTARS. Some progress had been made on identifying Federal, and State funding sources, and some ideas about possible commercial clients had emerged. A memo to W. Campbell, Code 935, dated April 30, described the status of the RVC effort at UC Davis. In particular, the memo set forth impediments to attracting commercial clients in agriculture, due to an unfortunate history in the region with remote sensing, and impediments to cooperation with CSTARS by significant centers and institutes at UC Davis, attributed to interagency rivalries, previous history, and notions of enchroached sovereignty.

In May 1997, a strategy was set forth to combat these impediments and stimulate the formation of an RVC at UC Davis: encourage their efforts to respond to the NRA-97-MTPE-05 announcement for centers of excellence in applications of remote sensing, and strongly encourage their efforts to respond to the CAN-97-MTPE-07 call for the establishment of a federation of ESIP III's. The rationale was: (1) the initial participants were principally researchers and academics, more comfortable with forming alliances to propose for grants, rather than to seek out commercial clients; (2) the funds offered directly by the NRA and CAN would motivate these groups to cooperate more immediately than pressing them to go out and find commercial clients; (3) in responding to the NRA, and in particular to the CAN, they would come to understand what the RVC concepts was, and how the ESIP III concept derives from it; (4) to respond successfully to the CAN they would *by necessity* have to go out, seek, and enter into agreements with commercial and other clients, in order to achieve a self-sustaining operation; and (5) if they were successful in building a response to the CAN, afterward the commercial clients might possibly press the affiliation to begin work on agreed tasks *prior* to any decision on the CAN, thereby pressing the affiliation to seek to form an RVC.

Over the months of May through July 1997 through J. Pierce, KT-Tech assisted in sheperding these efforts through Dr. S. Ustin, director of CSTARS, by providing consultation and information about the RVC system and network to possible participants in the affiliation and

to possible clients. In May 1997, KT-Tech, through J. Pierce, helped resolve obstacles impeding cooperation between the Center for GIS studies at UC Davis, and CSTARS sufficiently to affect cooperation in responding in June 1997 to the NRA with a proposal for a center of excellence for climate, environment and water resource assessments in California. The affiliation attracted one commercial client, the Electric Power Research Institute (EPRI), based at Palo Alto, CA.

Bouyed by the cooperation for the NRA, KT-Tech, through J. Pierce, pressed S. Ustin to enlarge the affiliation and scope of activity to respond effectively to the CAN. KT-Tech assisted in negotiations to resolve the roles to be played in the "ESIP/RVC" by the Center for Image Processing and Integrated Computing (CIPIC) at UC Davis, and the UC Davis large database management effort, part of the UC San Diego supercomputing initiative. In these negotiations KT Tech served as a consultant for the RVC, explaining what the objective of the RVC program was, what the architecture of an RVC was, how the RVC net was emerging, and the distinctions between the RVC concept and the ESIP III concept. In late June and July, negotiations expanded to include a principal State environmental agency, the California Environmental Resources Evaluation Service (CERES), as well as an additional committment from EPRI. KT-Tech, through J. Pierce also provided information to the consortium on Earthstation hardware, factors involved in ingesting and managing heterogeneous, environmentally-based data, and factors involved in the networking and administrative operations of such centers, as evidenced by the RVC's.

With the completion of the CAN proposal in mid July 1997, KT-Tech, through J. Pierce, advanced to S. Ustin and the affiliation that to maintain their momentum and their client base, it was important for them to begin at least nominal activity, preferably under the aegis of an RVC. Coincidentally, EPRI pressed S. Ustin to begin preliminary work, rather than wait for (and regardless of) the outcome of the CAN. On July 25, S. Ustin sent to W. Cambell, Code 935 a first draft for a letter of intent to establish an RVC at UC Davis, opening negotiations on the intent.

During the tenth quarterly period, August 1 - October 31, 1997, KT-Tech, Incorporated continued, broadened or initiated activities for Code 935 in four areas. In the area of image geo-registration it completed development on the first versions of two contributions to the registration toolbox being developed for the RVC's. Also, it inaugurated the development of the second version of the more promising of the two registration algorithms. In the area of spectral analysis, KT-Tech made explicit its approach, tasks, and possible data products arising from a multi-scale approach to feature extraction from spatially distributed spectral data. KT-Tech had initiated inquiry into this avenue of investigation in the last month of the ninth quarter. KT-Tech continued its activity to foster the establishment of an RVC at UC Davis, and to foster the development of two quite promising data products by CSTARS for use in the RVC's. Finally, KT-Tech completed its major objective to port the RVC database and management system to a Sun/Unix environment. KT-Tech began the task of porting the RVC database and management system to the SGI environment.

I. Registration Activity

At the end of the nineth quarterly period, KT-Tech had completed the development of version 1.0 of its original registration algorithm based upon linear wavelet decomposition techniques for the registration working group directed by Dr. J. LeMoigne, and had completed a MatLab-based beta version of a computationally rapid way to register images based upon nonlinear wavelet compression and singular value decomposition techniques. Scheduled for the tenth quarter were: the completion of version 1.0 for the SVD-based algorithm, performance and validation tests for both algorithms, the refinements for both algorithms, based upon the tests, and the completion of program documentation for the algorithms. Pending at the end of the tenth quarter were: the mechanism for delivering the code and documentation for the algorithms, the formal installation of the codes into the toolbox, and decisions on whether to continue development of a version 2.0 for the SVD-based algorithm which heightens its accuracy and capability, and broadens the use of its registration modules as a back end to other feature extraction routines.

Registration using nonlinear wavelet compression and SVD tools.

During the tenth quarter, KT-Tech completed the development of an algorithm to rapidly register nonlinearly compressed images using singular valued decomposition (SVD) techniques. This registration activity was to involve J. Pinzon and J. Pierce, initiate July 1 and complete version 1.0 by September 30.

By August 18, 1997, J. Pinzon and J. Pierce had completed and debugged a working version algorithm in MathLab, and had begun to transcribe the main modules into C. During his tenure at Code 935, August 18th-August 29th, J. Pinzon completed coding the algorithm in C and installed the principal modules into the suite of algorithms which was to evolve into the registration toolbox: the wavelet compression module, the hot pixel extraction module, the singular valued decomposition module, and the registration module. First versions of the stability feedback loop, and the registration refinement loop also were installed. Because priorities at the time required Wei Xia to direct her attention towards RVC development activity, consultations with Dr. J. Le Moigne and Wei Xia lead to the decision to postpone the activity of interfacing of the code with the Sun-based Khoros graphics interface to September. Subsequently, because of the demands of the RVC development, the activity of interfacing the code had to be postponed until after November. On August 22, J. Pinzon delivered an informal presentation of the registration algorithm to the registration working group at Code 935.

While J. Pinzon was at NASA GSFC, J. Pierce completed the mathematical analysis establishing the validity of using SVD techniques to register images, and continued the analysis of refinements for the stability feedback loop. He produced the first draft of the paper to be presented at the November registration workshop.

In September 1997, J. Pinzon and J. Pierce, completed the performance and validation tests on the code, in accordance with the protocal set forth by J. LeMoigne for tools for the registration toolbox. The results of the tests were delivered to J. LeMoigne September 26, 1997. From the tests, J. Pinzon and J. Pierce identified refinements for the program, particularly in the

stability and registration feedback loops. They also identified those conditions in the image which inhibit the performance of the algorithm; in particular, the presence of clouds. These observations spawned two avenues of inquiry which would produce a more effective version 2.0 algorithm. One avenue addresses the wavelet compression stage, and is discussed below. The other avenue addresses the use of a cloud filtering front end, which is based upon spectral feature extraction work. This avenue is addressed further below in the spectral analysis section.

By September 15, 1997, J. Pinzon and J. Pierce completed and submitted the paper "Image registration by nonlinear wavelet compression and singular value decomposition" for the CESDIS/IEEE Registration Workshop at GSFC in November 1997. The paper describes the algorithm, sets forth its mathematical basis, summarizes how the code implements the algorithm (particularly the feedback loops), presents a summary of the performance and validations tests, and concludes with observations on the strengths and vulnerabilities of the algorithm, and avenues of inquiry for producing a version 2.0. The paper was accepted by the workshop, and was to be presented by J. Pinzon in November 1997. In addition, J. Pierce and J. Pinzon produced a more complete Program Documentation.

During September 1997, J. Pinzon and J. Pierce submitted to KT-Tech and Code 935 avenues for improving the algorithm through a version 2.0, and means by which modules in the algorithm could be utilized by other programs which need to register images, but which input information other than that for which the program was originally intended.

The first avenue of development for Version 2.0 is the use of the Steerable Pyramid tool to improve in the algorithm the extraction of control points by wavelet compression. This tool overcomes the vulnerability in the Version 1.0 of the algorithm which arises from the lack of translation invariance in a wavelet decomposition. In September and October 1997, J. Pinzon and J. Pierce established the viability of incorporating this tool in preliminary work. This work was the basis of the abstract for the paper "Image registration by steered, nonlinear wavelet

compression directed by neural nets and singular value decomposition", submitted to the AeroSense'98 conference, April 1998.

The second avenue of development arose from the discussion following the presentation by J. Pinzon to Code 935 in September 1997. From comments by Pat Coronado, it appeared there was interest in registering images of hyperspectral data to GPS-based ground control points. Although the registration algorithm was not developed for input consisting of images and GPS data, its modules were directly relevant. Because of the modular nature of the algorithm the registering stages of the algorithm were distinct from the compression stages. In particular, the SVD computation and SVD-based registration modules would still supply quick accurate registration as the back end of a registration algorithm in this context. Indeed, even elements of the front end compression could be used, viewing the GPS information as an *a-priori* ensemble of reference control points, and extracting control points from the input image by the algorithm. The stability feedback loop would monitor the extraction of control points from the input image, and the registration feedback loop would optimize the registering parameters by working solely on the ensemble of control points from the input image.

Registration using the Low-Low component of a linear wavelet decomposition

At the end of the nineth quarter KT-Tech, through J. Pinzon and J. Pierce, had begun testing the algorithm developed by E. Kaymaz to geo-register images using the Low-Low component of a linear wavelet decomposition of reference and input images. These tests revealed instabilities in the program, and KT-Tech was engaged in isolating those elements in the code which precipitated the obstruction, and in assessing if the obstacle is fundamental to the design of the algorithm, or an error in the code implementing it.

In September, KT-Tech corrected the means by which the program isolated its computation of the translation parameters from the registration parameters. This correction eliminated the loss of convergence in the registration refinement loop, which had caused the instability in the program. Validation and performance tests were then carried out, in accordance

to the protocol set forth by J. LeMoigne for tools from the registration working group. The results of these tests were delivered to J. LeMoigne September 26, 1997. The results and discussions with J. LeMoigne on September 19, 1997, suggested how to refine of the program, and how it is possible to integrate this "Low-Low" component algorithm with the "Low-High" and "High-High" algorithms developed by J. LeMoigne and M. Mareboyana. Discussions on this activity continued through October and were left open, pending decisions by Code 935 on the nature of its support for registration efforts.

II. Spectral Analysis Activity

In the nineth quarter KT-Tech, through J. Pinzon and J. Pierce initiated discussion with Code 935 to isolate avenues of activities relevant to the RVC's in feature extraction from spatially dependent multi and hyper spectral data. In the Nineth Quarterly Report KT-Tech submitted an abstract outlining three avenues of activity involving the use of multiscale resolution in the spatial and spectral domains which, in presentation to Code 935 and in subsequent discussion with T. Gualtierri and J. LeMoigne, had proven to be relevant and intriguing. In the tenth quarter, KT-Tech pressed to render these avenues of activity more concrete, with the intent to develop specific activities relevant to Code 935's objectives.

In August 1997, KT-Tech, through J. Pinzon, established three concrete, specific areas of activity in spectral analysis directly interfacing Code 935's current efforts, and which would utilize multi-resolution tools to analyze spatially dependent spectral data: connections of HFBA and support vectors, HFBA and cloud removal, spectral unmixing, and HFBA and RVC applications. The first combines spectral feature extraction using the HFBA technique developed at CSTARS, with applications to hyper/multi-spectral images; spatial-spectral feature extraction. It develops how HFBA could be integrated with wavelets to produce unsupervised and supervised image classification. The second activity addresses cloud removal and describes how HFBA could complement the ongoing work by J. Le Moigne, C. Tucker and M. Smith. The third addresses how on-the-fly feature extraction based upon spectral redundancies could prove

quite useful in processing in real or near time hyperspectral data from instruments flying on the UAV.

In September and October 1997, preliminary work by J. Pinzon, with the assistance of J. Pierce, proved promising. The work became the basis for two papers detailing the multi-scale approach to spatially dependent spectral data, which serves as the basis for advancing the avenues of activity listed above. The abstract for the paper, "Robust spatial and spectral feature extraction for multi-spectral and hyper-spectral imagery", was submitted to the AeroSense98 conference in Orlando FA, in April 1998. The abstract for the paper "Robust feature extraction for hyperspectral imagery using both spatial and spectral redundancies" was submitted to the JPL workshop on hyperspectral processing, Pasadena Ca, November 1997.

At the end of October 1997, J. Pinzon presented to Code 935 a summary of the activites being formulated. Two topics of discussion arose from the presentation: how to distinguish explicitly the contexts in which approaches to classification support vectors had advantage over approaches using principal components, and how could spectral redundancy be exploited to produce near and real time spectral classification.

III. <u>RVC Code Porting Activity</u>

In the tenth quarter KT-Tech, through the efforts of Renlan Liao, had completed the port and ad tested the integration of the RVC code from the HP environment to the SUN UNIX environment. At the end of the nineth quarter, by working closely with Code 935 and GST, KT-Tech had secured a SUN Ultra 1 workstation as a testbed, and had secured the necessary licensed software for SUN versions of the Object Store, and media by which the various elements of the RVC system communicated. By that time, Renlan Liao had ported the principal modules to the SUN environment. Pending were the ports of revisions of the modules, the system integration, and the testing, validation, and certification of the system.

During month of August, KT-Tech completed the porting of the then current and emerging versions of the various modules of RVC including: User Interface Module, Ingest Module, Database Module, Planner/Scheduler/Dispatcher Module. Working with GST personnel, KT-Tech, through Renlan Liao, constructed a test server to validate the interface. By the end of August, KT-Tech had completed the port of the eight major module, had tested them individually, and had initiated the system integration activity.

During month of September, KT-Tech, through Renlan Liao, announced at the RVC workshop its completion of the port, test, and validation of the operation of the eight major modules in the RVC system operating in the SUN UNIX environment. on the Sun workstation serving as a test server. By mid September, at the time of the RVC workshop, only system integration problems remained to be resolved. At that time, Renlan Liao confirmed that the system integration would be completed by September 30, 1997, as originally projected. Working closely with Bob Cromp and GST personnel, the system integration was completed and the integrated system running in the Sun UNIX environment was tested and proven functional by September 30, 1997.

To confirm that the RVC system running in the Sun UNIX environment was fully operational, KT-Tech had to test it on actual RVC data, as opposed to simulated data. In October 1997, KT-Tech successfully tested the system operating in the UNIX environment on two small satellite images. However, to fully test the system, KT-Tech required another 8 Gigabyte hard drive for the test server to store the large GOES and NOAA images. Through Bob Cromp specifications were filed to aquire the drive.

At the end September 1997, Code 935 requested KT-Tech, in consultation with GST, to begin the port of the RVC to the SGI environment. In October 1997 KT-Tech on site at Code 935 started the project to port the RVC to the SGI environment, specifically the IRIX 6.3. KT-Tech, working with personnel from GST installed Tcl 7.4, Kk 4.0, Diffutil 2.5 and RCS5.7 on the SGI machine on site at Code 935.

By the end of October 1997 KT-Tech, through Renlan Liao, had ported the following modules to the SGI environment: Curator, sqt, and Scripts.

IV. RVC Activity

In the tenth quarter KT-Tech, through J. Pierce, continued its efforts to shepherd the establishment of an RVC at UC Davis, and to foster the production of data products and tools relevant to RVC activity. KT-Tech continued to operate on the strategy of pressing S. Ustin to maintain the momentum and the affiliations developed for the responses to the NRA-97-MTPE-05 (Center of Excellence in Applications of Remote Sensing and CAN-97-MTPE-02 (ESIP III) announcements by finalizing an RVC letter of intent and inaugurating RVC activity prior to, and independent of, the announcement of these awards. During the last week of July, the effort had produced a first draft of a letter of intent, submitted as a memo to Bill Campbell.

In August 1997, the strategy showed more promise when UC Davis was announced as a recipient of a NASA NRA as a center of excellence in applications of remote sensing. The grant, strictly for hardware, would enable CSTARS to purchase an AVHRR earthstation. It was hoped at the time that this achievement could be used to leverage in two ways: to gain an endorsement by the College of Agriculture and Environmental Science to the president of the university to obtain the letter of intent, and to obtain a contract from EPRI (Electric Power Research Institute) to begin work proposed with EPRI in the NASA CAN, using funds formally committed by EPRI in the CAN proposal.

In September 1997, these efforts were set back, because of two developments. First, efforts to obtain the endorsement of the college were hampered, because of a challenge for endorsement by another group in the college seeking a focus on plant genetic engineering. Second, discussions with R. Bernstein, director of the Disaster Planning and Mitigation Target for EPRI, revealed that his group was in negotiation with Lockheed-Martin on tasks paralleling those proposed with CSTARS in the NASA CAN. Consequently, R. Bernstein, himself, would not commit funds prior to the award of the CAN. However, CSTARS was invited to present to

the power companies forming the target group data products which the group could consider and possibly decide to fund.

In light of these developments, activity in August began to shift towards: (1) maintaining the involvement by CSTARS in the RVC activity, and (2) seeking ways to involve CIPIC, the center for image processing and integrated computing at UC Davis, in the RVC activity.

In September 1997, S. Ustin pressed to cement her relationship with the Disaster Planning and Mitigation Target Group in EPRI. The August EPRI news letter target group announced its partnership with UC Davis in the NASA CAN. Also, S. Ustin was invited to deliver an address on the use of remote sensing and NASA data products for disaster monitoring and assessment at the annual target meeting in Phoenix, Arizona, in October.

In September, S. Ustin, assisted by J. Pierce, attended the RVC workshop and presented the first drafts of data products CSTARS was developing for EPRI, as an example of emerging UC Davis RVC activity. Regretably, because of a lack of communication between S. Ustin and W. Campbell, the objectives of the presentation had been mutually misinterpreted. S. Ustin sought to present an example of a commercially viable RVC data product, W. Campbell sought the state of progress towards the establishment of an RVC entity, regardless of product. In consequence, the lack of interaction doomed the prospect of a letter to support the effort to gain endorsement from the College of Agriculture, further hindering the effort to achieve a letter of intent from the university.

In light of this setback, effort by KT-Tech refocused on how CSTARS at UC Davis might serve as a source of data products relevant to the Goddard and other RVC's. At the RVC workshop three avenues emerged.

First, through KT-Tech, CSTARS could definitely assist Code935 in engaging C. Sailor to assist in the porting of the image processing software Majestic to the RVC. C. Sailor is at Davis CA, and (in keeping with her husband) seeks an affiliation with UC Davis. CSTARS can

provide that affiliation, and provide (along with CIPIC) adequate facilities to enhance the porting of the software. This idea was advanced to J. Garegnani on the final day of the RVC workshop in September. When presented with the idea subsequently, C. Sailor expressed definite interest.

Second, in his presentation, and in the remarks made by W. Campbell afterward, Steve Maher conveyed the significance and importance of developing ways of rendering in 3D changing to rapidly changing environmental data. To accomplish this objective novel developments in graphical rendering and rapid selection would be required. Such investigations wee a principal interest to B. Hamann the leader of the visualization thrust of CIPIC. In particular, he was quite experienced and had the laboratory facilities to implement hierarchical data structuring of geometrically positioned data for rapid rendering, selection, and smaller scale examination. Also, CIPIC was acquiring a 3D Immersive WorkBench, in keeping with Steve Maher's direction for RVC graphics rendering. In light of these observations, and with the agreement of B. Hamann, J. Pierce sent on September 30 an inquiry to Steve Maher about the possibility of discussing mutually beneficial activity.

Third, at the RVC workshop, N. Rische spoke on the development of a semantic-based object-oriented database, to be used in the future for RVC applications. It occurred that it might be particularly effective if data products and graphical rendering were also developed in such a hierarchical data structure paradigm. After the RVC workshop, J. Pierce presented the idea to B. Hamann and D. Rocke, leader of the massive computation thrust at CIPIC. Both expressed interest in the idea, and certainly interest in learning more about the database. With their approval, J. Pierce contacted N. Riche, who expressed definite interest in such an approach

In October 1997, effort focused initially on competing for funds from EPRI previously committed formally, subject to the award of the NASA CAN. On October 16, J. Pierce, speaking for S. Ustin presented "Current and Future NASA Data for Disaster Assessment & UC Davis/EPRI Activity" to the Disaster Planning and Mitigation Technologies Target Utility Advisors Group at the annual meeting of EPRI in Phoenix AZ. In the presentation J. Pierce

displayed two emerging data products from the CSTARS group: one directed towards the impact of severe weather and flood of electric power transmission systems, the other toward the monitoring and prediction of wildfires in wilderness regions. In each scenario, J. Pierce discussed the importance of use remote sensing data and models in conjunction: to assess and monitor vulnerability and resourse marshalling stategies at the pre-event stage, anticipating what's happening at the time of the event (using models), and assessing damage and recovery at the post-event stage. The RVC concept was presented as an overview, illustrating with the data products the idea of client-oriented data product development.

During the eleventh quarterly period, November 1, 1997 - January 31, 1998, KT-Tech, Incorporated continued its activities for Code 935 in the area of the porting of the RVC, now known as the RAC, completed its contributions for the registration toolbox, and terminated its efforts to develop activities in the area of spectral analysis.

For the task of porting the RAC, during this quarter KT-Tech began porting the database and management system to the SGI environment. KT-Tech also stress tested the the completed RAV in the SUN UNIX environment, and began its final packing for the release.

In the area of registration, KT-Tech completed the protocol for the release to the registration toolbox of the two registration algorithms developed in the previous quarters. The C code for the algorithm based upon the Low-Low component of a wavelet decomposition of the registering images was installed into the toolbox and successfully interfaced with Khoros environment. At the USRA/CESDIS Image Registration Workshop, KT-Tech presented a paper on the nonlinear wavelet registration algorithm. A second paper which reported the next generation design of the nonlinear algorithm was submitted and accepted for presentation at the SPIE AeroSense'98 conference. The paper was subsequently withdrawn when support for further development of the registration activity was removed.

In the area of spectral analysis, KT-Tech proposed its design for integrating multi resolutional tools, with spectral mixture analysis and the support vector approach to produce a

means for automatic or supervised feature extraction from spatially dependinet multi and hyper spectral data. The work produced a paper accepted for the SPIE AeroSense'98 conference.

I. RAC Code Porting Activity

In the eleventh quarter KT-Tech, through the efforts of Renlan Liao, initiated the port of the RAC code from the HP and SUN UNIX environments to the SGI environment. At the end of the tenth quarter, by working closely with Code 935 and GST, KT-Tech had completed port and tested the integration of the RVC (RAC) code from the HP environment to the SUN UNIX environment. Pending for the release of the code was a stress testing of the port, an ugrade of the ODI to a newer version.

In November 1997, KT-Tech, through Renlan Liao, ported the PSD, RVCI and Geewiz packages to the SGI environment. Technical difficulties were encountered, due to the differences among the communication and C, C++ libraries on SGI, SUN, and HP. KT-Tech developed means to efficiently translate communication modes and access libraries for these three systems. In December 1997, KT-Tech installed and validated the operation of ALLEGRO COMMON LISP from FRANZ INC., and OBJECTSTORE from Object Design on SGI system. KT-Tech also began to port the Planner-Scheduler-Dispatcher module and ODI module, which is the object oriented database server of RAC system. In January, KT-Tech began to port to the SGI IRIX 6.3 a newer version of ODI, the object-oriented database part of the RAC. KT-Tech received this version of the ODI in mid January. KT-Tech encountered some segmentation fault error messages. KT-Tech is now negotiatin with Technical support from Object Design - maker of ObjectStore - resolve these segmentation difficulties.

During the eleventh quarter KT-Tech overcame hardware access and software availability problems to complete the certification of the RAC in the SUN UNIX environment through stress testing the system. By the end of the tenth quarter, KT-Tech had completed the RAC system integration in the SUN UNIX environment, proven the system functional, and had certified that the system was operational by testing it on two small satellite images. It remained to test the

system fully on GOES and other NOAA images. This required additional hardware, in particular, an 8 GigaByte hard disk for image storage. In October 1997, with the help of Bob Cromp, KT-Tech ordered for the SUN Ultra 1 workstation 2 hard drives, each with 4.2 Gb capacity, for the purpose of building a testbed to stress test the RAC in the SUN/UNIX environment. In November 1997, KT-Tech received the SPAECstorage MultiPack which was needed for the stress test of the RVC. In December 1997, KT-Tech, with the help of GST personal, was able to acquire and enable one of the hard drives. It was cross mounted to the SGI IRIX 6.3 workstation so as to serve as a storage area for the porting to SGI. In January 1998, KT-Tech was able to acquire the second drive and perform the stress testing for the RAC in the SUN environment.

In mid-January 1998, KT-Tech received a newer version of ODI, the object-oriented database part of RAC. The newer version replaced the "RogueWave" library with a customized library. By the end of January 1998 and the eleventh quarter, KT-Tech was working on the final packing of RAC on SUN Workstation in preparation for the release of it to Kansas University RAC center. The preparation included: modifying make files, modifying configuration files and testing automatic installation scripts.

II. Registration Activity

During the eleventh quarter, KT-Tech completed its two contributions to the registration toolbox, negotiated the release of the codes, installed the first of the two algorithms, and terminated its efforts to develop either algorithm further.

Registration using the Low-Low component of a linear wavelet decomposition

At the end of the tenth quarter, KT-Tech, through J. Pinzon and J. Pierce, had examined the code developed by E. Kaymaz to geo-register images using the Low-Low component of a linear wavelet decomposition of reference and input images and had isolated elements which contributed to instabilities in its performance. KT-Tech also identified elements in the wavelet

decomposition and reconstruction algorithms which supported all wavelet-based routines in the toolbox. These elements could contribute to an inherent uncertainty for all algorithms which called these routines for wavelet decomposition.

In November 1997, KT-Tech, though J. Pinzon and J. Pierce, amended the code for the algorithm itself to correct instabilities in the registration caused by an improper cropping of the image and an instabilitiy in the successive approximation routine. KT-Tech also revised the structure of the code to produce a more modularized code. Such a structure would open the code for future developments, whereby it might be merged with the algorithms using the Low-High/High-Low and the High-High componets of the wavelet decomposition.

In December 1997, KT-Tech discovered an additional source of inherent error in the algorithm arising from two sources in the compression and reconstruction algorithms of J. LeMoigne, which are called by this routine. The first source of error arose when the compression algorithm overwrote an "indata" file, treating it as a temporary file. Because of a parameter which is fixed in some subroutines and called by others, the compression of images larger than 128 X 128 caused a loss of significant portion of original image, resulting (under reconstruction) in random gray level pixels. KT-Tech assessed that this phenomenon was a principal reason why its algorithm would not converge sharply to a specific set of registration parameters. KT-Tech corrected the problem by erecting an "indetails_LL" file to which "indata" outputs its Low-Low components prior be being overwritten, and by dismissing the call to the reconstruction routine.

In addition, KT-Tech identified a variable casting problem arising from interfacing the wavelet compression algorithms with the Khoros GUI. The wavelet compression routines produce float variables; the Khoros interface requires integer variables to produce its displays. Until this time, the practice of recasting the float variables as integers and "losing" the pointers to the float variables with the overwriting of the "indata" files had been of minor consequence. However, recasting the wavelet coefficients from float to integer would truncate their

representation, commonly called "quantization". The action would introduce inherent error for routines which would extract features from the wavelet coefficients for the purpose of registration. KT-Tech corrected its algorithm to protect the integrity of the float variables until the registration was complete, then recasting variables for display by Khoros.

In January 1998, the amended C code for the Low-Low component based algorithm was released to J. LeMoigne, successfully interfaced with the Khoros environment, and installed in the toolbox.

Registration using nonlinear wavelet compression and SVD tools.

By the end of the tenth quarter, KT-Tech, through J. Pinzon and J. Pierce had completed the development of a second registration algorithm which used a nonlinear wavelet compression and Singular Value Decomposition tools. The algorithm had been developed as a MatLab code and had been validated using the testbed developed by J. LeMoigne for algorithms for the registration toolbox. KT-Tech was engaged in two efforts at that time: casting this version of the algorithm into C code and interfacing it with the Khoros environment, and developing the second version of the algorithm which would utilize a Steerable Pyramid to achieve more robust and more accurate results.

In November 1997, J. Pinzon presented the paper "Image Registration by Non-Linear Wavelet Compression and Singular Value Decomposition" at the USRA/CESDIS Image Registration Workshop, held at GSFC. The paper described the nonlinear wavelet based algorithm and presented the results of the validation tests. Also, it outlined the developments for the second version of the algorithm.

Because of budget cutbacks, in December 1997, KT-Tech decided it could no longer support further development of any registration algorithm. In particular, when the paper "Image registration by steered, nonlinear wavelet compression directed by neural nets and singular value decomposition" was accepted for presentation at the AeroSense'98 conference in April 1998, the

authors were forced to withdraw the paper. KT-Tech could not bear the cost of preparing the document and presenting the paper.

Rather, in December 1997 and January 1998, KT-Tech limited activity on this project to coding the algorithm in C. Because of scheduling problems and task revisions required by the budget cutback for the registration toolbox, J LeMoigne requested that KT-Tech submit only the Low-Low component algorithm for the version 1.0 of the toolbox, and reserve the nonlinear wavelet algorithm for submission to version 2.0 of the toolbox.

III. Spectral Analysis Activity

At the end of the tenth quarter KT-Tech, through the efforts of J. Pinzon, assisted by J. Pierce, had developed proposals for activity in three areas related to classification and feature extraction from spectral data. The work became the basis for two papers detailing a multi-scale approach to spatially dependent spectral data. The abstract for the paper, "Robust spatial and spectral feature extraction for multi-spectral and hyper-spectral imagery", was submitted to the AeroSense98 conference in Orlando FA, in April 1998. The abstract for the paper "Robust feature extraction for hyperspectral imagery using both spatial and spectral redundancies" was submitted to the 7th JPL Airborne Earth Science Workshop in Pasadena CA, in January 1998.

During November 1997, KT-Tech continued to try to align its spectral analysis activity to directly support ongoing activity at Code 935. In particular, KT-Tech addressed the problem of how to distinguish explicitly the contexts in which approaches to classification using support vectors would have advantages over approaches using principal components, and how the multi-resolution tools of wavelets and HFBA would augment the classification using support vectors. KT-Tech also prepared a summary of these ideas on HFBA which was sent to J. Garegnani and R. Cromp for further consideration.

Because of budget cutbacks, in December 1997, the government program managers decided they could no longer support further development of registration algorithms. KT-Tech

negotiated with S. Ustin and the CSTARS lab, UC Davis, to assume partial support of this effort, simply to keep it alive. As a consequence, when SPIE notified KT-Tech of the acceptance of the abstract for the paper "Robust spatial and spectral feature extraction for multi-spectral and hyper-spectral imagery", for the AeroSense'98 Conference in April 1998, KT-Tech released to CSTARS the rights to complete the development of this work and present it at the conference. Likewise the paper for the 7th JPL Earth Science Workshop was presented under the aegis of the CSTARS lab in January 1998.

During the twelfth quarterly period, February 1, 1997 - April 30, 1998, KT-Tech, Incorporated continued its activities for Code 935 in the area of the porting of the RAC, and expanded the documentation on its contributions for the registration toolbox.

For the task of porting the RAC, during this quarter KT-Tech continued the porting of the RAC database and management system to the SGI environment. KT-Tech also stress tested the the completed RAC in the SUN UNIX environment, and prepared the final packing for its release to the University of Kansas. KT-Tech also engaged in porting the latest version of the RAC from the HP environment to the SUN UNIX environment.

In the area of registration, KT-Tech delivered its program documentation for the registration algorithm based upon the low-low component of the linear wavelet decomposition of the images under investigation, delivered a complete set of validation and performance tests for the algorithm, and delivered the program documentation for the registration algorithm based upon the nonlinear wavelet compression of images using singular value decomposition techniques.

I. RAC Code Porting Activity

At the end of the eleventh quarter, KT-Tech, through the efforts of Renlan Liao, had anticipated completing the port of this newer version of the ODI to the SUN UNIX environment, completing the stress test of the RAC on the SUN, packing and releasing Sun-based RAC to the

University of Kansas, porting the current version RAC to the SGI IRIX6.3, helping GST personnel working on the next generation of RAC, which would use switch board communication protocol, porting the next generation of RAC to the SUN Solaris operating system, and porting the next generation of RAC to the SGI IRIX 6.3.

In February and March 1998, KT-Tech advanced its efforts to port the RAC from the HP UNIX platform to SGI IRIX 6.3 operating system, and to develop the testbed and protocols to stress test the RAC in the SUN/UNIX environment. KT-Tech pressed to port a new version of ODI, the object-oriented database part of RAC, to Sun Workstation, resolving the different ways HP-UNIX and SUNUNIX deal with the Null pointer. KT-Tech continued its work on the final packing of RAC on SUN Workstation in preparation for the release of it to Kansas University RAC center. The preparation included: modifying make files, modifying configuration files and testing automatic installation scripts. KT-Tech also completed its efforts to develop the testbed and protocols to stress test the RAC in the SUN/UNIX environment.

In April 1998, KT-Tech completed its stress test of the RAC in the SUN/UNIX environment. Eleven real time satellite images from 5 AVHRR bands and assorted GIF images were used in the test. The RAC was able to ingest, index and store the information. Subsequently, tests to query the database, find the image produce and retrieve data product orders proved successful.

Also in April 1998, KT-Tech was able to significantly advance its porting of the latest version of the RAC from the HP environment to the SUN/UNIX environment. This version uses Tcl 8.0 and Tk 8.0 for the interface and includes some other changes in each module.

II. Registration Activity

During the twelfth quarter KT-Tech, through the efforts of J. Pinzon and J. F. Pierce, complemented its documentation of the two registration algorithms KT-Tech had delivered to the Registration Working Group prior to and by the end of the eleventh quarter. In February 1998,

KT-Tech delivered the program documentation for the registration algorithm based upon the low-low component of the linear wavelet decomposition of the images under investigation. In March 1998, KT-Tech delivered a complete set of validation and performance tests for the algorithm.

During the thirteenth quarterly period, May 1, 1998 - July 31, 1998, KT-Tech, Incorporated continued its activities for Code 935 in the area of porting the Regional Applications Center (RAC) database and management system to the SGI environment.

During May 1998, KT-Tech ported the latest version of Regional Application Center (RAC) from the HP to the SUN workstation environment. Working with the designer for each module, KT-Tech modified the original code and Makefiles, so that the same code could work both on the HP and the SUN systems. Modifications were made to the Makefiles following modules: Gant, Curator, PSD, Ingest, Rcvi, and ODI 1.9.

Working with personnel from GST, KT-Tech also started to develop and test an installation package which is user-friendly and grammar-proof. To fully test the installation package, KT-Tech installed the new package on a clean Sun workstation, Badu, and ingested real time satellite images (NOAA12, NOAA14 and GOES) into the system.

KT-Tech also worked out the environmental differences between HP UNIX and SUN UNIX and addressed them in the install package.

Starting this quarter, KT-Tech began to maintain for each month an archive of the notes which record the changes in the various modules of the RAC code that were required to enable the porting to the various environments and the integration of the codes for the various systems. For June 1998, the notes being placed in the log were those related to the modifications of the Makefiles described above, those related to the port to the workstation Badu, and those related to the modifications to accommodate the module ODI 1.9. These notes were meant to serve as a source of reference for the formal effort to document the RAC program.

In June 1998, KT-Tech continued with its efforts to port the latest changes of RAC from the HP to the SUN workstation environment. Working with the designer for each module, KT-Tech continued to modify changes in evolving code and Makefiles as they arose, so that the same code could work both on the HP and the SUN systems. During this month, modifications for the SUN port were made to the Makefiles of the following modules: Gant, ODI, Ingest, and in the ODI/RAC schema. Modifications were made also in the Parser header to reflect the migration from C pointers to LISP elements.

KT-Tech also continued to work out the environmental differences between HP UNIX and SUN UNIX. Changes in the environment for the SUN were included in the .rvc_env file.

In July 1998, work continued on porting revisions of the RAC and on refining the installation package, making it more user friendly. Renlan Liao began orienting and training Claudia M. Casteneda. During this period the porting process was explained, and a protocol written explaining the steps followed and the environment under which the work was done. It was decided that KT-Tech effort should be directed towards the implementation of the dispatcher and to this end an initial meeting with Dr. R. Bane took place to give an overview of the system as it was at thetime. Dr. Bane explained the new design ideas that he had in mind and his requirements for the language to be used in this implementation. From this meeting it was agreed that further work with the Common Lisp Object System (CLOS) was needed. KT-Tech prepared a basic plan to approach these new tasks. It was decided that there would be at least one weekly meeting with Dr. Bane where revision of short term goals and discussions would take place.

During October 1998, the program COLLAGE, a domain independent planning system was run with an example previously written by Dr. Amy Lansky. The core of the program would run. However, its elements but like the GUI would not run because it was written in an old version of Tcl/Tk which was not compatible with the version installed on the computer being

used. Therefore, KT-Tech, started focusing on ascertaining how the program worked in order to be able to insert it into the RAC system.

The planner takes a set of specifications, e.g. facts, constraints, relations, bindings, and resources, and generates a plan accordingly. Initially, KT-Tech had to find out the way in which the specifications were read into the plan so that input files could be presented to the planner directly.

KT-Tech also had to be able to articulate the existing elements in the PSD module with the new one. These tasks were to be coordinated by Dr. Bane through a main weekly meeting and secondary ones as needed.

APPENDIX A

RVC SOFTWARE MODULE
IMPROVEMENT REPORT

NASA CONTRACT NUMBER: NAS5-32893

FIRM NAME: KT-Tech, Incorporated

FIRM ADRESS: 9801 Greenbelt Road
Suite 314
Lanham, Maryland 20706

DELIVERY DATE: May 1, 1997

RVC Software Module Improvement Report

As a part of its contract deliverable with NASA, during the period March 3 - April 30, 1997, KT-Tech has started working on the RVC code porting from HP environment to SUN UNIX. KT-Tech has started studying the system and its requirements and has been in close contact with Government and GST personnel involved in the implementation of the original system.

The RVC system includes four major modules:
1)Algorithm
2)Query Interface
3) Planner-Scheduler-Dispatcher(PSD)
4)Database

KT-Tech has finished porting of the Algorithm part and in the process of porting the Query Interface. KT-Tech is still waiting for the tool packages necessary for porting the PSD and Database part of the system.

1. ALGORITHM

This package was developed by Samir Chettri. It includes 11 objects:

Veg_Index_avherr, Computes a Vegetation Index for a given scene on the ground. Takes bands 1 and 2 of an AVHRR image and computes a "greenness index" or a "vegetation index". High values of vegetation index indicate pixels with high proportions of green biomass. The input files are unsigned short ints and the output file is unsigned byte. Vegetation index is formed as:

$VI = N/D$, where

$N = (AVHRR\ Channel\ 2 - AVHRR\ Channel\ 1)$

$D = (AVHRR\ Channel\ 2 + AVHRR\ Channel\ 1).$

Pclouds_avhrr, Obtains a cloud mask for AVHRR images. Takes bands 1 and 4 of an AVHRR image, calibration files for both bands, navigation for the images; user provided thresholds for albedo and temperature (band 1 is the visible channel

and band 4 the infrared- therefore it is appropriate to use the terms albedo and temperature respectively) and produces a cloud mask.

To get all the clouds in the image, the user may have to vary the thresholds. This is due to the large variation in cloud top temperature and reflectivity. In addition, it is possible to have high reflectivity in parts of the image depending on the positions of the sun with respect to the sensor (this phenomenon is called sun glint).

Pconvert_raw-mac_header: program to take raw file and convert to a Mac header file as required by the RDC viewer

Wavelet, Computes the wavelet transform of an image. The wavelet transform in one dimension takes a signal and filters it to produce a new output signal of the same length as the input. The output signal consists of two parts. The first part (in fact the first half) consists of the low pass filtered input signal and the second part consists of the high pass filtered input signal. One can recursively perform the same filtering operations on the low pass part of the data (i.e., the first half by convention). Each recursion is a "level" in the wavelet transform with the first filtering operations being level 1.

The filtering procedure may be extended to 2 dimensional signals (i.e, input images). Much like the two dimensional Fourier Transform, the rows and columns can be treated independently. What we now get is an output image (of the same size as the original image) that is divided into four parts LL, HL, HH, LH(clockwise from the upper left, by convention). Where LL= the original image lowpass filtered in the horizontal and vertical directions; HL = highpass filtered in horizontal, lowpass filtered in the vertical; HH = highpass filtered in both directions; LH = lowpass filtered in horizontal, highpass in the vertical. Again, we can recursively perform this operation on the LL image for as many levels as the data will permit. What we get is a sequence of images representing different frequency and spatial information in the image.

Snow_and_Ice, Obtains snow and ice regions in an image. Takes bands 1 and 2 of an AVHRR image and computes the snow and ice cover by creating three new

image bands. The input files are unsigned short ints and the output files are unsigned byte. The algorithm is described below:

* Output Band 1: 4*AVHRR Band 2-3*AVHRR Band 1
* Output Band 2: AVHRR Band 2
* Output Band 3: AVHRR Band 1

The computed bands form the RGB channels of a new 3 band image. This algorithm was provided by Bene Shaffer who called it "Albert Arkin's algorithm".

Pnn_random_select
Pkmeans
Pfire_avhrr
Phisto
Edge_detect
Io_test.

This algorithm package was developed using a programming tool called **Khoros** which is a software integration and development environment. It provides a rich, set of programs for information processing, data exploration and data visualization. Multidimensional data manipulation operators include pointwise arithmetic, statistic calculations, data conversions, histograms, data organization, and size operator; image processing routines and matrix manipulation are also provided. Interactive data visualization programs include an image display & manipulation package, an animation program, a 2D/3D plotting package, a colormap alteration tool, and an interactive image/signal classification. In addition, 3D visualization capabilities are also offered; a number of data processing routines for 3D visualization are provided, along with a software rendering application. The Khoros operators are generalized, such that each can solve problems in a variety of specific areas such as medical imaging, remote sensing, process control, signal processing, and numerical analysis.

The goal of the Khoros software is to provide a complete application development environment that redefines the software engineering process to include all members of the project group, from the application end-user to the infrastructure programmer. Khoros is a comprehensive system that may be viewed in different ways, depending on your scientific needs and objectives.

For every Khoros object in Samir's package, KT-Tech needs to go through the following steps: create object, make clean, make klint, make Makefile, make, make install. Since it uses an in-house developed library "LibIDSO.a", KT-Tech also need to port this library to Sun platform. Following changes were made to insure its successful compilation on Sun:

1)LibIDSO.a/ OrbitTools.h uses an include file <sys/timers.h>, Sun does not have such a file. After inspection of the functionality of this file, KT-Tech decided to use <time.h> instead, and add "#define TimeOFDAY 1" in the same file.

2)Since the byte order in HP and Sun are different, byte switching function swap was used in many places. KT-Tech added (char *) in front of many variables to silence the compiling warning message (see appendix 1).

3) In Tools.c, logf() and expf() were used for floating point calculation. Those two functions were defined in <math.h> on HP. On Sun, there is no function for floating point. After close evaluation, KT-Tech decided to use log() and exp().

2. RVC QUERY INTERFACE

RVC query interface is a Graphical user interface to the database. With this tool you can find out what images are in the holdings by making a query based on constraining any combination of the following attributes:

    Platform-sensor-channel
    Time
    Bandwidth
    Image content
    Location.

After the appropriate constraints are selected, the query is submitted with a button-push on the user interface's panel. If the query can be satisfied, the hits are displayed as marks on the map representing image centers for those items in the holding that match your query. Typically after this step you will "browse" through your hits. You do this by selecting a few (or many, or all) of them, and push another button. At this point, a thumbnail representation of each granule in your selection is displayed inside a

new window. Now you can decide if you want to order a particular product related to this image. Products either already exist, or are generated by running any of the available programs applicable to your chosen image. In either case, you are presented with a choice from a menu associated with the image. After you complete your choice, the product generation will be initiated asynchronously by the system to the server. You will automatically receive an e-mail with information on how you can retrieve your requested products when your request has been completed.

The Query interface was developed using Tcl and Tk. **Tcl** is actually two things: a language and a library. First, Tcl is a simple textual language, intended primarily for issuing commands to interactive programs such as text editors, debuggers, illustrators, and shells. It has a simple syntax and is also programmable, so Tcl users can write command procedures to provide more powerful commands than those in the built-in set.

Second, Tcl is a library package that can be embedded in application programs. The Tcl library consists of a parser for the Tcl language, routines to implement the Tcl built-in commands, and procedures that allow each application to extend Tcl with additional commands specific to that application. The application program generates Tcl commands and passes them to the Tcl parser for execution. Commands may be generated by reading characters from an input source, or by associating command strings with elements of the application's user interface, such as menu entries, buttons, or keystrokes. When the Tcl library receives commands, it parses them into component fields and executes built-in commands directly. For commands implemented by the application, Tcl calls back to the application to execute the commands. In many cases, commands will invoke recursive invocations of the Tcl interpreter by passing on additional strings to execute.

An application program gains several advantages by using Tcl for its command language. First Tcl provides a standard syntax: once users know Tcl, they will be able to issue commands easily to any Tcl-based application. Second, Tcl provides programmability. All a Tcl application needs to do is to implement a few application-specific programming interfaces for building up complex command procedures. By using Tcl, applications need not re-implement these features. Third, extensions to Tcl, such as the Tk toolkit , provide mechanisms for communicating between applications by sending Tcl commands back and forth. The common Tcl language framework makes it easier for applications to communicate with one another.

Note that Tcl was designed with the philosophy that one should actually use two or more languages when designing large software systems. One for manipulating complex internal data structures, or where performance is key, and another such as Tcl, for writing smallish scripts that tie together the other pieces, providing hooks for the user to extend.

Tk is an extension to Tcl which provides the programmer with an interface to the X11 windowing system.

To ease the process of porting this interface, Query interface's designer and developer George Fekete decided to use a Project Revision Control System called PRCS. PRCS is the front end to a set of tools that like CVS and provides a way to deal with sets of files and directories as an entity, preserving coherent versions of the entire set. Its purpose is similar to that of SCCS, RCS, and CVS, but (according to its authors, at least), it is much simpler than any of those systems.

To prepare for installation of PRCS-1.1.1, KT-Tech has downloaded and installed following packages on its SUN at CODE 935:

0)**gdb-4.16**: The GNU Debugger. the purpose of a debugger such as GDB is to allow you to see what is going on "inside" another program while it executes-or what another program was doing at the moment it crashed. You can use GDB to debug programs written in C, C++, and Modula-2.

1)**gcc-2.7.2**: GNU project C and C++ compiler. The C and C++ compilers are integrated. Both of them process input files through one or more of four stages: preprocessing, compilation, assembly and linking.

2)**libg++-2.7.2**: the GNU C++ library. libg++ is an attempt to provide a variety of C++ programming tools and other support to GNU C++ programmers. libg++ is not intended to be an exact clone of libc from AT&T. For one, libg++ contains bits of code that depend on special features of GNU g++ that are either different or lacking in the AT&T version, including slightly different inlining and overloading strategies, dynamic local arrays, etc. All of these differences are minor. The library is designed to be compatible with any 2.0 C++ compiler.

3)**texinfo-3.9**: GNU's hypertext system. The GNU project has a hypertext system called Info which allows the same source file to be either printed as a paper manual, or viewed using info. It is possible to use the info program from inside Emacs, or to use the stand-alone version.

4)**make-3.75 (gnu)**: a utility that automatically determines which pieces of a large program need to be recompiled and issues commands to recompile them. You need a file called "makefile" to tell make what to do. Most often, the makefile tells "make" how to compile and link and program.

5)**tex-7.0**: a typesetting system: it was especially designed to handle complex mathematics, as well as most ordinary text typesetting. Tex is a batch language, like C or Pascal and not an interactive "word processor": you compile a Tex input file into a corresponding device-independent (DVI) file (and then translate the DVI file to the commands for a particular output device). this approach has both considerable disadvantages and advantages.

6)**emacs-19.34**: an extensible, customizable, self-documenting real-time display editor. It provides facilities that go beyond simple insertion and deletion: controlling subprocesses; automatic indentation of programs; viewing two or more files at once; editing formatted text; and dealing in terms of characters, words, lines, sentences, paragraphs and pages, as well as expressions and comments in several different programming languages.

7)**autoconf-2.12**: a tool for producing shell scripts that automatically configure software source code packages to adapt to many kinds of UNIX-like systems, The configuration scripts produced by Autoconf are independent of Autoconf when they are run, so their users do not need to have Autoconf.

8)**m4-1.4**: an implementation of the traditional UNIX macro processor. It is mostly SVR4 compatible, although it has some extensions (for example, handling more than 9 positional parameters to macros). "m4" also has built-in functions for including files, running shell commands, doing arithmetic, etc.

KT-Tech has downloaded and installed on its SUN workstation at Code 935 Tcl7.6 and Tk4.2 and made the necessary changes to ensure that they ran without any

problems on that platform. KT-Tech has also started porting of RVC Interface from HP to SUN. The following changes have been made:

1) In the Makefile, add "/usr/openwin/include" in front of <X11//XLib.h>

2) On HP, string compare function "strcmp(*S1, *S2)" returns NULL when string S1 equals to string S2. On SUN, the same function returns 0 when S1 equals to S2. So in /extensions/Tree.c, line 310, 314, 318, 325, "strcmp(*S1, *S2) == NULL" were changed to "strcmp(*S1, *S2)== 0"

3)In /extension/gyHierbox.c, line 1555, "(Tcl_FreeProc *) was inserted in front of the function name Tcl_eventuallyFree().

4)On HP platform, constant MAXINT is defined in <ctype.h> ; on SUN, it is defined in <values.h>. KT-Tech added the line "#include <value.h>" in /regions/chull.c.

5)In /communication/hush.c, it uses system variable Idnumber to create hush table. On HP platform, Idnumber is defined in /sys/utsname.h, structure utsname. SUN also defines structure utsname in /sys/utsname.h, but the structure does not have a member called "Idnumber". After close investigation, KT-Tech decided to use a system call "gethostid()", which is defined in <sys/unistd.h>.

6) Since the RVC interface uses a Tcl Extended library, KT-Tech has downloaded and installed tclX7.6.0 on its SUN workstation at Code 935.

SCHEDULER, PLANNER AND DISPATCHER

This part of the package provides a planner/scheduler/dispatcher capability to handle: disk space management for data ingest, basic browse product generation and menu-driven product generation.

It was developed using **Allegro Common Lisp** which was ordered in March 1997. KT-Tech is still waiting for its arrival before the porting process can start. Meanwhile, KT-Tech has done some preparation work for the porting of this part of the system.

To insure a smooth process of porting SPD to SUN platform, SPD's designer and developer Dr. Bob Bane decided to use a version control system called "CVS". Using it, you can record the history of your source files. For example, bugs sometimes creep in when software is modified, and you might not detect the bug until a long time after you make the modification. With CVS, you can easily retrieve old versions to see exactly which change caused the bug.

CVS also helps you if you are part of a group of people working on the same project. It is all too easy to overwrite each others' changes unless you are extremely careful. Some editors, like GNU emacs, try to make sure that the same file is never modified by two people at the same time. Unfortunately, if someone is using another editor, that safeguard will not work. CVS solves this problem by insulating the different developers from each other. Every developer works in his own directory and CVS merges the work when each developer is done.

KT-Tech also downloaded and installed CVS-1.9, RCS5.7 and Diffutil on its SUN workstation in Code 935. RCS is a system for version control; Diffutil is a utility that will display line-by-line differences between pairs of text files.

DATABASE

The primary persistent data storage area for the entire RVC system. It is also used as an index mechanism to all data stored in the RVC and support rapid search of that data. It also serves as a persistent storage for curator policy decision, algorithm representation. and resource descriptions.

This package was developed using ObjectStore. Object Design's ObjectStore product family leads the object-oriented database industry in deployments, performance, service and quality. It is a complete data management solution for developers of dynamic, interactive, high-performance applications for the Web and other distributed computing environments. The latest version ObjectStore5.0 provides an interface to Java which allows you to create Java applications that store application objects in its high performance, high-availability multi-user ODBMS; your Java applications can also access C++ objects stored in the database. It has replication capabilities that automatically distribute copies of your ObjectStore data to remote machines, in real-time,

so that everybody has fast, local access to ObjectStore data, no matter how geographically dispersed they are.

The original ObjectStore only works on HP platform. Since version 4.0, it also works on UNIX platform. An order for version 4.0 was placed in March 97, KT-Tech is still waiting for it to arrive before it can start the porting process.

This part of the package also use a library called Tools.h++: for Sun from Roguewave. It provides a couple of classes used in the database such as date, time and string manipulation functions. KT-Tech needs to use objectstore compiler that comes with Sun for porting the package. Some of the C++ code, makefile and C code also needs to be modified to run on Sun. KT-Tech also needs to resolve the compiler to compiler issue for this part of the package.

Diagram 1

PORTING PROGRESS CHART   5/1/97
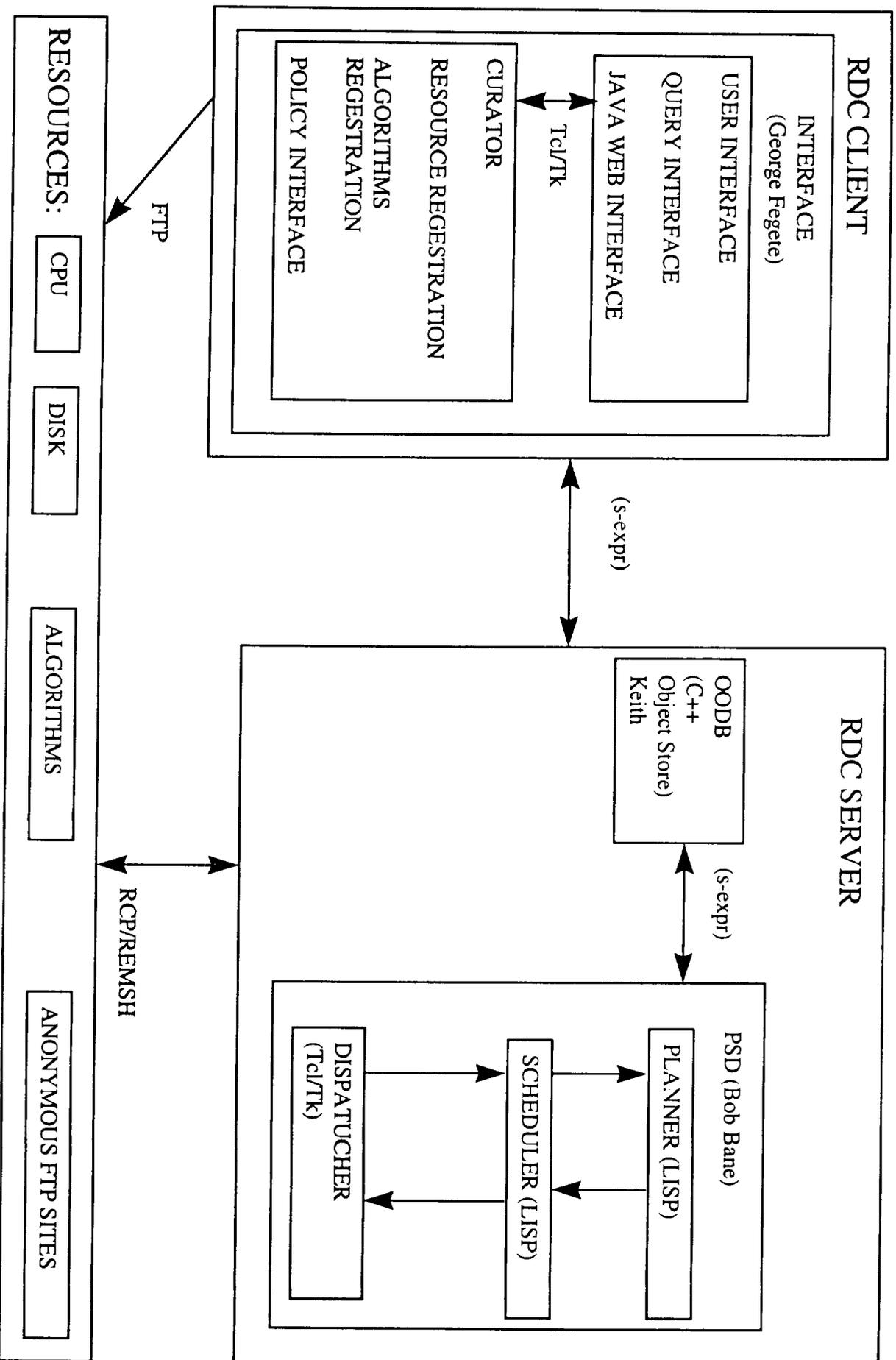
	Software Pkg needed	Program	Porting	Evaluation	Estimated Time Line
Algorithm	Khoros, Ansi-C	Available			
Samir	Installed		Done 3/21		One week.
Query	Tk4.2, Tcl7.6 TclX7.6 Installed	Available 4/17			
Interface					One month
George	Prcs, installed				
P-S-D *	Lisp				1 month after receiving the software
Bob Bane	Ordered in Mid March				
Database	ObjectStore 4.0				1 month after receiving the software
Keith	Ordered in Mid March				
Computer	Order at Beginning of March				
Integration					1 month after everything works

--Renlan Liao

APPENDIX

```
GVARTools.c:     swab((char *)&bHeader[i].WordCount, (char *)&tmpShort, 2);
GVARTools.c:     swab((char *)&bHeader[i].ProdID, (char *)&tmpShort, 2);
GVARTools.c:     swab(&aInfo->Information[6014], (char *)&aSounder-
>Detector.AScanLine, 2);
GVARTools.c:     swab(&aInfo->Information[6016], (char *)&aSounder-
>Detector.BScanLine, 2);
GVARTools.c:     swab(&aInfo->Information[6018], (char *)&aSounder-
>Detector.CScanLine, 2);
GVARTools.c:     swab(&aInfo->Information[6020], (char *)&aSounder-
>Detector.DScanLine, 2);
GVARTools.c:     swab(&aInfo->Information[6022], (char *)aSounder-
>Detector.PixelNumber, 11 * 2);
GVARTools.c:     swab(&aInfo->Information[6368], (char *)aSounder-
>Detector.Channel, 11*4*19 * 2);
GVARTools.c:     swab(&aInfo->Information[64], (char *)&aNLUT->DetectorXCount,
2);
GVARTools.c:     swab(&aInfo->Information[68], (char *)&aNLUT->DetectorYCount,
2);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->A[0], aNLUT-
>DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->A[3983],
aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->A[7966],
aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[526], (char *)&aNLUT->B[0], aNLUT-
>DetectorYCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->B[3757],
aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->B[7740],
aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[978], (char *)&aNLUT->C[0], aNLUT-
>DetectorYCount);GVARTools.c:         swab(&aInfo->Information[74], (char
*)&aNLUT->C[3531], aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->C[7514],
aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[1430], (char *)&aNLUT->D[0],
aNLUT->DetectorYCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->D[3305],
aNLUT->DetectorXCount);
GVARTools.c:         swab(&aInfo->Information[74], (char *)&aNLUT->D[7288],
aNLUT->DetectorXCount);
GVARTools.c:  swab(&Info[0], (char *)aData->RawWord, 250*2);
GVARTools.c:  swab(&Info[500], (char *)aData->StatusWord, 2 * 2);
```

```
GVARTools.c:    swab(&aInfo->Information[DetectorStart+32], (char *)aDetector-
>shortData, aDetector->Documentation.LPIXLS*2);
GVARTools.c:    swab((char *)&tempShort1, (char *)&tempShort2, sizeof(short));
OrbitTools.c:    swab((char *)Buff2, (char *)Buff, 12);
RipTools.c:      swab(Buff, (char *)aScan.ID, 194);
RipTools.c:       swab(RawSwab, Raw, RawSize);
SEATools.c:      swab((char *)PNCnt, (char *)PNCnt, 2);
SEATools.c:      swab((char *)PNErr, (char *)PNErr, 2);
```