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3.4 REPORT OF THE SUBPANEL ON INTER-IMA MATCHING

The inter-image matching panel met for two sessions to define research needs in this subject area for earth resource observation systems. The panel consisted of:

Mr. H. K. Ramapriyan
NASA/GSFC

Mr. R. Bryan Erb
JSC

Ms. June Thormodsgard
USGS

Mr. Jerry M. Cantril
Computer Sciences-Technicolor Associates

Mr. Frederick W. McCaleb
NASA/GSFC

Mr. George Austin
Lockheed

Mr. Donald Brandshaft
Santa Barbara Research Center

Mr. Paul F. Maynard
Earth Satellite Corporation

Mr. Terry Silverberg
U of MD

Mr. Richard Sigman
Department of Agriculture

Professor Laveen Kanal
U of MD

The survey paper prepared by R. Wolfe and R. Juday provided a good overview of the state of the art and requirements. The panel concentrated upon developing the design of and rationale for research efforts in this area.

3.4.1 Recommended Research

Six research areas were identified by the panel and are described below:

I. Correlation Considerations

The issues to be addressed under this topic are those relating to matching small sections of images (or information derived from images) to other images (or map-derived information). We recommend considering the following topics: a) types of correlation algorithms, b) preprocessing techniques, c) limits on subpixed accuracy, d) relief and atmospheric refraction effects, e) evaluation of success rate, f) evaluation of accuracy.

We are aware of various matching and preprocessing techniques as indicated in the survey paper. However, a study is still needed to compare these from the points of view of interactions among them and their effects on accuracy of matches. A study should be made of the theoretical limits on the subpixed accuracy that can be achieved given that the images are sampled data. The validity of techniques used for estimating "subpixel offsets" (e.g., surface fitting) for matching maps should be examined. The effects of relief and atmospheric refraction on the image-matching process should be quantified, especially in relation to higher resolution sensors. Techniques should be developed for estimating probabilities of image matching success, false-alarm and miss rates.

The correlation techniques to be considered should include "nonraster" data types. Extraction of image features to match with "digital map" representations should be considered due to its potential for a common data base for multiple sensors. Different data types may require different algorithms. Both sensor data correlation and the required preprocessing should be studied. A tradeoff study should be made to find the optimum combination of preprocessing correlation and surface fitting for offset estimation in relation to various sensor types (resolution, spectral characteristics, geometrics), ground characteristics, and imaging seasons.

If correlation techniques guaranteeing successful image matching are not available and verified, the specifications such as the Thematic Mapper equipment of .3 (relative) and .5 (absolute) accuracy cannot be met. It has been shown that hard specifications such as these imply high ground system costs. Therefore it is necessary to establish realizability of such accuracies so that we either not be as stringent with the specifications and let users "live with" the errors, or come up with techniques for achieving and verifying the accuracies. Multisensor image matching and image to nonimage data matching techniques have the potential of saving the effort needed in building multiple control point libraries.

Items a through d listed below constitute a coherent group. The prioritization should be in terms of theoretical work and the experiments to be performed on various sensor types, data types, etc The sequence of events should be as follows: a) create a common software brary to be shared among researchers; b) perform theoretical studies of : pixed accuracies, relief distortions and atmospheric refraction effects; c) identify sensor types and experimental data sets (synthetic and real) to be used; d) conduct tests of technicians and trade off studies.

II. Study to determine interaction of inter-image matching procedures and selection of GCPs for a given sensor.

The types of GCPs which should be selected for future libraries will most likely depend not only on the characteristics of the GCP, but also on the matching procedures in which the GCPs will be used. For remote sensing data from a given sensor, an experimental design with the following analysis elements is proposed: a) preprocessing procedure analysis, b) inter-image matching factors analysis (correlation measure, correlation peak determination, match reject/accept criteria), c) GCP factors analysis (type of GCP, season and scene characteristics of base chip, season and scene characteristics of test chip).

Within each factor combination, chip pairs with known image-to-image matches (determined manually) will be subjected to the processing factors. Measured response data for the experimental design will be matches and summary statistics (average, dispersion, percentiles) of the difference between true offset and automatically determined offset for nonrejected matches, and measures of the temporal stability of matching performance. The benefits of the above described study are that the study conclusions will provide guidance in selection of GCPs for future libraries. The penalties for not performing the study is that future GCP libraries will be built but will have low success rate in automatically registering data.

III. Global multisensor control point library feasibility study.

If ground control points are to be used to rectify and/or register future remotely sensed image data, the feasibility of a highly automated, global, multisensor control point library should be determined. Such a system should incorporate improved methods of loading control points, improved user access (including the capability for users to interactively load their own control points from remote terminals), standard control point formats, and a multisensor data base.

A global multisensor control point library would reduce the operational costs associated with precision rectification and registration of future sensor systems. In addition, the capability for users to load special sets of GCPs and access the GCP library allows the user to guarantee the rectification and/or registration accuracy of specific data sets of interest to him.

The initial capital outlay to implement such a system would probably be in excess of $10 million. In addition, multisensor registration may well not be easy to achieve.

IV. Multiple Control Point Considerations

Elevation of observed control point mismatches to an image-level mismatch characterization is effected by fitting a distortion function to the GCP offsets. This distortion function could arise from (1) inadequacy in a priori definition of the geometrical model (e.g., not including scan anomalies, terrain effects, atmospheric differential refraction, etc.), (2) from an incomplete characterization of its form (e.g., role is modeled as third-order in time but the data is first order), or (3) the case that the a priori model is properly characterized but with imprecise parameters (e.g., polynominal coefficients are refined with GCP data). Characterization of the model dictates the optimal sizing and placement of control points. The possibility of undetected GCP outliers (i.e., erroneous matches) dictates the need for estimation techniques beyond conventional least squares.

The proposed research would investigate the effect of number and distribution of control points required as an effect of image (sensor) characteristics adequacy of fit to an a priori model or selection of degree or model for warping function in an adaptive sense. The adaptive capability will reduce the number of correlations required for mapping well ordered data sets and consequently the processing time or equipment complexity while extending the capability to handle diverse data sets at limited throughput rates.

The following specific areas are recommended: a) Investigate spatial distortion filtering; derive new techniques or expand existing techniques, e.g. Kahlman filtering; b) Test polynomial rubber sheeting in terms of compromise between order selection and reducing RMS error; c) Investigate application of robust estimation techniques to rubber-sheeting and to fitting a pricri forms; d) Investigate adaptive placement of control points, e.g., to effect minimum RMS fit errors; e) Investigate magnitude of high-frequency geometrical distortions (atmospheric distortion, sensor anomalies) and control point sizing; f) Investigate methods to overcome geometrical distortions with a GCP patch.

Candidate methods include iterative registration (correlate, remap, recorrelate, remap, etc.) and application of the affine/Fourier technique of Emmert and McGillam to determining the offset in an affinely distorted GCP.

V. Centralized System Study

A trade-off study needs to be undertaken that considers the optimal hardware configuration for image production of data derived from different sensor types with emphasis on software/hardware tradeoff for balanced computation and I/O. Of particular interest is the need to determine feasibility of developing a centralized system to perform registration and rectification for various sensors (i.e., SAR, MLA, MSS, etc.). Development of a centralized system could be the most economical and efficient approach to meet future image processing requirements.

VI. User System Studies

By using a combination of systems analysts, a survey of user experience, and experimental tests, it should be possible to determine the speedup factors a user can expect by using commercially available special purpose hardware such as array processors and bulk core memory. It should also be possible to determine whether it is economical to speed up commonly used algorithms by using simple custom electronics. This study would assist users in hardware systems design.

3.4.2 Research Priorities

Priorities for the proposed research are subdivided in Figures 1 and 2 into near- or long-term tasks. The elements listed are subsets of the six recommended research areas.

NEAR TERM

TYPES OF CORRELATION ALGORITHMS

PREPROCESSING TECHNIQUES

STUDY W.R.T. SENSOR/GEOMETRY/SPECTRAL CHARACTERISTICS/
RESOLUTION/SEASON/GROUND CHARACTERISTICS

EVALUATE SUCCESS RATE AND ACCURACY

MULTISENSOR REGISTRATION

ADAPTABILITY OF GCP'S FOR DIFFERENT SENSORS

STUDY OF SUBPIXEL ACCURACY QUESTION

STUDY OF HARDWARE ARCHITECTURE

ROBUST ESTIMATION TECHNIQUES

EVALUATION OF RELIEF DISTORTION

Figure 1. Near term recommendations for Research

LONG TERM

INVESTIGATE FEASIBILITY OF NON-
OR MINIMUM-GCP REGISTRATION
(IMPROVED SYSTEMATIC ACCURACIES)

MULTISENSOR REGISTRATION
SAR, MSS, TM, MLA
PASSIVE MICROWAVE RADIOMETER

CORRECTION OF RELIEF DISTORTION

Figure 2. Long Term Recommendations
For Research