A SURVEY OF IMAGE PROCESSING DEVELOPMENTS IN SUPPORT OF REMOTE SENSING

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A SURVEY OF IMAGE PROCESSING DEVELOPMENTS IN SUPPORT OF REMOTE SENSING

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1.0 Introduction

New algorithm developments for image processing (IP) will occur throughout the 1980's, resulting from evolution in computer hardware and sensors as well as continuing research. This report will describe the areas of algorithm development that are occurring in applications, research, and operational environments. Included is an overview of image processing activities at institutions which are generally regarded as leaders in IP algorithm development and implementation. Finally, this report addresses directions in IP algorithm development that are being proposed for the EROS Data Center (EDC). The major applications of IP at EDC are developed for use in the processing, analysis, and extraction of remote sensing information from Landsat and aircraft data (platforms).

2.0 Background

Currently, for Landsat multi-spectral scanner data, one spectral band of information requires storage of approximately $9x10^6$ bytes of data. For the Landsat follow-on satellite, the thematic mapper sensor data will require approximately $38x10^6$ bytes of storage per band. For many applications, more than one band must be processed at the same time. Most of the constraints associated with IP algorithm development are imposed by the vast quantities of data that have to be processed before the analyst can view the finished product.

Algorithms for IP can be generalized as follows (Hunt, 1976):

1. Sum of products

$$F_{jk} = \sum_{m,n} h_{mnjk} f_{mn}$$

2. Fast transforms

$$F_{jk} = \sum_{m,n} f_{mn} W^{jm+nk}$$

3. Point mappings

$$F_{jk} = \emptyset (f_{mn})$$

where f_{mn} are points of sampled image

h_{mn} are weights

W is the kernel of the transform

$\emptyset$ is a non-linear function

F_{jk} is the output image

Sum of products computation are used in convolution, restoration, enhancement, and resampling to different projections (Hunt, 1976). The fast transforms are used for all the above, as well as transform domain interpolation, image statistics and estimation parameters, and for image bandwidth compression. The point mapping functions are used for enhancements, gray-scale mappings, and generation of pseudo-color. These algorithm developments will be paced by certain hardware developments.

2.1 Digital Image Processing Hardware Considerations

Special purpose computers are being designed for each of the above functions (see Figure 1). There are special purpose, highly parallel computers for certain IP functions. The system described in Figure 1 is capable of providing the computational power of a CDC 7600 for 250-300K. The evolution of data base (DB) computers will greatly influence the design and availability of algorithm development. DB computers will handle data sets of 10^9 bits at typical transfer rates of 3×10^9 bits per second to the host or array processor for computational purposes. Real-time displays are also being considered which will transfer data on the order of 10^8 bytes per second through a large multi-port I/O bus. The display devices are capable of digital refresh black-and-white imagery presented at 30 frames per second for 512x512x8 bits and 1024x1024x8 bits (x3 for color).

For the smaller user though, a more exciting development is the creation of micro-computer based image processing systems. For example, a system comprised of a DEC PDP 11/23 with an FPS 100 array processor is presently being designed, which gives the user the power of a PDP 11/34 at a fraction of the cost. The FPS 100 is an array processor with 300 ns memory and an instruction set similar to the FPS AP120B. The PDP 11/23 is very similar to the LSI 11 micro-computer except that the 11/23 has floating point hardware and the full 11/34 instruction set. The price for this system with appropriate I/O hardware is on the order of 50-100K. Other low cost systems are being proposed for state and local governments in the 25 to 30K price range. It is anticipated that once this kind of hardware is made available to so many users processing remote sensing information, many new developments in IP will be achieved.

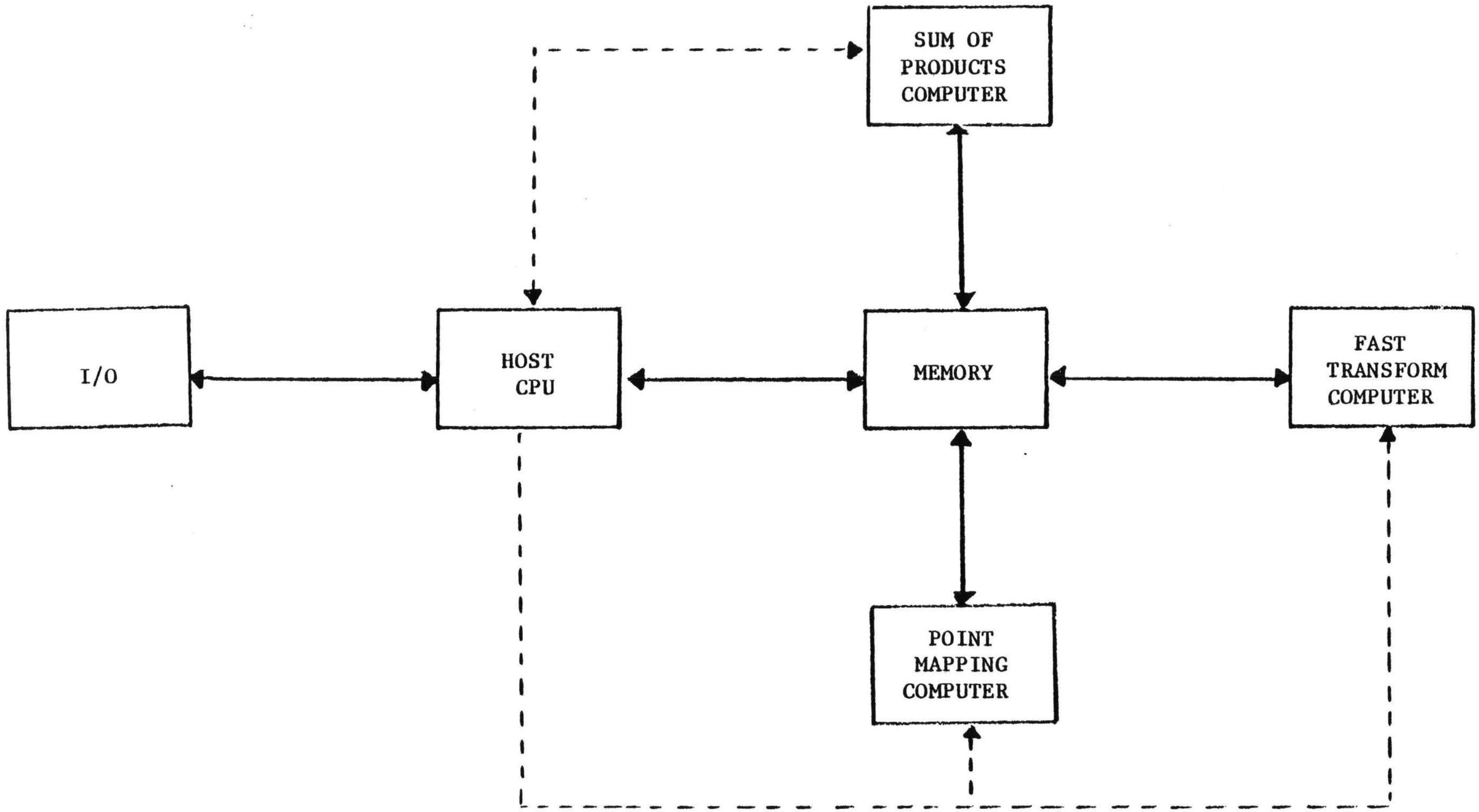

Figure 1. Specialized IP computing system

Another hardware development, that will rival the impact array processors have had on IP, is mass store devices. Once the user has on-line access to 10^{13} or 10^{15} bits of data, it is possible to do multi-date processing of data on a lot larger volume of information than has ever been available in the past. Again, IP algorithm development will occur as people push the information derivation capacity of various techniques. Image summary statistics will play a much larger role in deciding what data an algorithm will be exercised on. Mass store systems are being planned with 10^{13} to 10^{15} bits on line with file access time on the order of 3 to 50 seconds and numerous users on line at once through host processors. Figure 2 illustrates an example of an IP information system of the 1980's.

To a certain extent, future planning for larger image processing computer systems will be driven by higher data rates from improved sensor resolution. Continual development in the image processing systems (or data management systems) of the 1980's will stress off-loading certain processes to front-end displays or specialized hardware to minimize I/O processing rates. However, with the advent of the combination of micros and array processors, IP in the low data rate environment will be very attractive to many users. Continual hardware improvements and the advent of memory cycle times on the order of 10^{-16} seconds through Josephson circuits will make large systems capable of higher throughput. The possibility of utilizing, ARPANET, for IP data transfer will also stimulate IP algorithm development in that it will expose more and more software designers to parallel coding techniques.

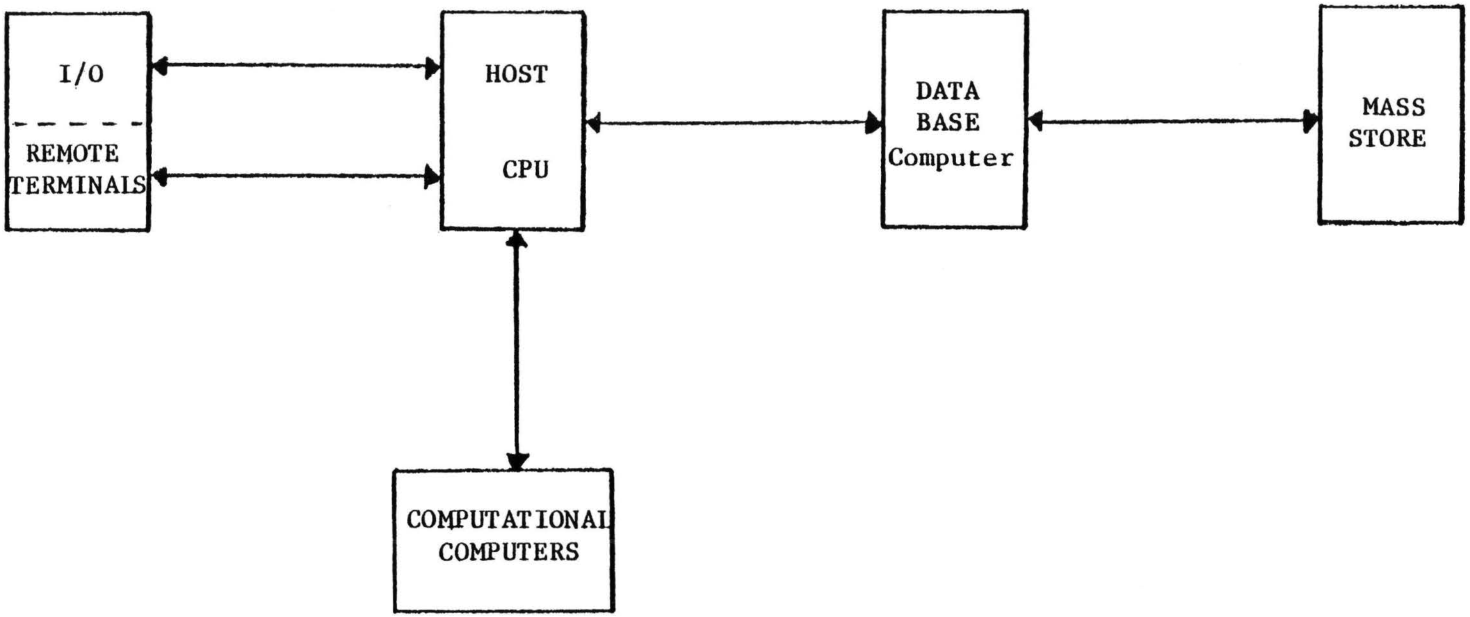

Figure 2. IP information system

2.2 IP Sensor Developments

Basically the sensor problems of the 70's concerning geometry and radiometry will still be with us through the 1980's. What will change with the new sensors such as the multiple linear arrays is high resolution and greater radiometric accuracy. Investigators are presently evaluating the electromagnetic spectrum of varying window sizes in attempting to derive new information out of the different divisions of the EMR spectrum. New sensors, however, will be developed that will utilize portions of the EMR differently than those now in use. More important information derivation techniques will occur as a result of new ways of combining data from different spectrums to enhance components of structure, color, and texture of targets as well as thematic material.

Developing sensors which utilize charge coupled devices (CCD) with metal oxide semi-conductor (MOS) integrated circuits will greatly influence real-time sensor IP over the next 5 to 10 years. Sensors intergrated to CCD's aboard satellites of the late 80's are proposed that will have the capability to process 10^6 pixels/second (1 pixel = 8 bits). Two-dimensional processing operations will also be possible utilizing fast transform algorithms at the sensor level. All of these sensor developments will allow programmable IP sensors to be available during the 1980's. Some of the operations suggested for these smart sensor chips are listed in Table 1. In Figure 3 is a diagram of the configuration of a CCD sensor with a processor on the same chip (Nudd, 1979).

In Figure 4 is the present configuration for information handling aboard satellites. The smart sensor will replace the sensor in Figure 2 with an integrated sensor and processor. Not only will the functions outlined in Table 1 be available, but the smart sensor will also be able

Table 1. IP algorithms integrated to chips (from Nudd, 1979)

TEST CHIP NUMBERS	ALGORITHMS IMPLEMENTED	KERNEL SIZE	OPERATIONS PER PIXEL	PERFORMANCE: NUMBER OF BITS	PERFORMANCE: SPEED (PIXEL RATE)	PERFORMANCE: EFFECTIVE OPERATION RATE	STATUS
I	EDGE DETECTION	3 x 3	16	4	5 kHz	80 KOPS	DEVELOPED AND TESTED
	HIGH–PASS SPATIAL FILTER	3 x 3	18	4	5 kHz	90 KOPS	
	LAPLACIAN	3 x 3	13	4	5 kHz	65 KOPS	
	12 dB/APERTURE CORRECTOR	3 x 3	18	4	5 kHz	90 KOPS	
II	SOBEL	3 x 3	16	4	2 MHz	32 MOPS	DEVELOPED AND TESTED
	MEAN	3 x 3	9	4	2 MHz	18 MOPS	
	UNSHARP MASKING	3 x 3	13	4	2 MHz	26 MOPS	
	BINARIZATION	3 x 3	10	4	2 MHz	20 MOPS	
	ADAPTIVE STRETCH	3 x 3	12	4	2 MHz	24 MOPS	
III	LAPLACIAN	3 x 3	13	6+	7 MHz+	91 MOPS+	IN PROCESS
	MASK PROGRAMMABLE	7 x 7	98	6	7 MHz	636 MOPS	
	PROGRAMMABLE	5 x 5	50	6	7 MHz	350 MOPS	
	PLUS SHAPED MEDIAN			6	7 MHz		
	BIPOLAR CONVOLUTION	26 x 26	1352	6	7 MHz	~10^4 MOPS	

+PREDICTED PERFORMANCE BASED ON DESIGN

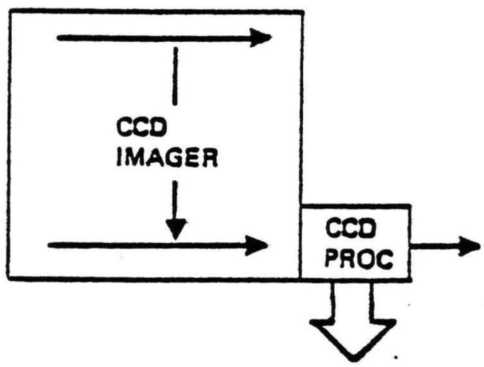

Figure 3. Technique for integrated CCD
images and processor

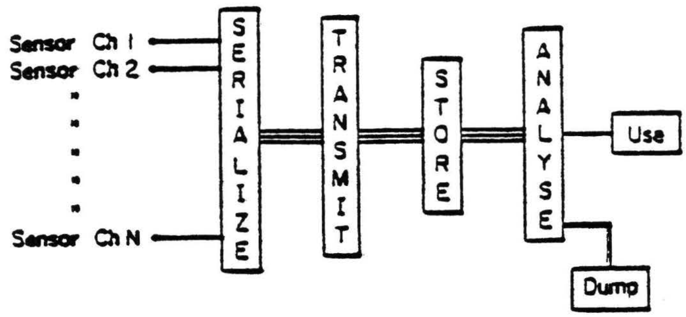

Figure 4. The data-handling sequence presently used

to sample the input data and decide aboard the satellite whether to down-link for further processing or dump. This decision process will compare stored data either on-board the satellite or up-linked for a specific pass so that redundant data is not down-linked for processing (R. Keman, et. al., 1977). Future smart sensors will revolutionize present modes of sensor data processing. In Figure 5 is a description of the smart sensor and a pre-processor with an editing or dump function.

3.0 Definitions

Because of some confusion among investigators about terminology in the areas of IP, definitions of the areas that will be addressed in this report are given below.

3.1 Coding

The subject of coding basically includes the subsets of data compression, formatting, data structures, data bases, and image segmentation. However, coding generally is the subject of how to create an invertible transform for a given image. The selected transform should also be more economical than the original image. This economy is generally expressed in bits per image or picture element (pixel). A limit of encoding capability is the original image entropy. Some methods of coding or data compression give 10 to 1 compression ratios with close to full restoration capability.

In obtaining image compression through coding, two techniques are generally used:

1. Fast Fouriers Transforms (FFT) where after the FFT is computed, the resulting coefficients are observed. Those coefficients with a magnitude below a certain level are

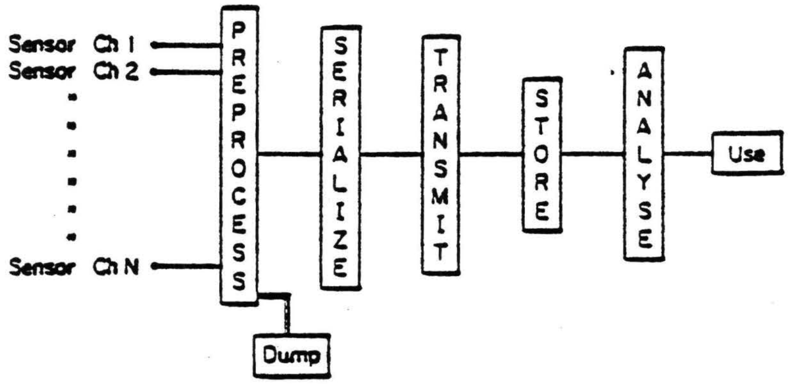

Figure 5. Data handling with a preprocessor in the sequence

eliminated. Then the inverse of the FFT is done, reconstructing the original image. The resultant image minus the detail of small magnitude, although not fully restored, does not appear that much different from the original.

2. Difference Methods: Where taking the difference between samples in either the spatial or temperal and then quantizing the results can result in full restoration.
3. Other methods are Huffman and block codes.

3.2 Restoration

These techniques assume that the observer has knowledge of the original image. In equation (1),

$$F_S(x,y) = S(s,y) * F_I(x,y)$$

the original image, $F_I(x,y)$, is convolved with the sensor function S(x,y) to produce a sampled image $F_S(x,y)$. In restoration methods,

$$\hat{S}^{-1}(x,y) * F_S(x,y) = \hat{F}_I(x,y)$$

$\hat{S}^{-1}(x,y)$ is convolved with the sampled image to produce an estimated image, $F_I(x,y)$. $\hat{S}^{-1}(x,y)$ is an estimate of the sensor or point spread function. For restoration methods to be successful, it is anticipated that the difference ε will be small. Of course, the smaller ε is, the better the restoration.

$$[F_I(x,y) - \hat{F}_I(x,y)] \leq \varepsilon$$

Most of the techniques of restoration are oriented to undoing degradation of the scene by the sensor and the processing system. Most of the techniques used, model the degradation to $F_I(x,y)$ as additive combinations of noise, blurring due to focus and motion, and atmospheric affects. The multiplicative affects such as sun angle are also modeled. Blurring is a weighted sun or integral operation, and is highly correlated. Noise, however, is uncorrelated.

The various restoration operators are Kalman and other two-dimensional filters. Also, pseudo-inverse or deconvolution techniques are also used (such as $\hat{S}^{-1}[x,y]$). Synthetic line generation is usually an example of a restoration technique (Bauer, 1978).

Restoration techniques also address the problems of quantitative radiometric and geometric correction. In radiometric restoration, one attempts to retain scene signature subtleties with the proper brightness range. Balance among sensors of the same wavelength is maintained to avoid banding. Lastly, photographic or shading corrections and pixel noise reduction are also restoration techniques. As far as geometric correction as a restoration process is concerned, the main objective is to register sequential images and to align data with that from other sources.

The two basic kinds of geometric correction are used for elimination of internal and external sources of error. The internal sources are made up of inter-sensor pixel displacement sensor or scanner non-linearities and horizontal and/or vertical inequalities in pixel spacing. The external sources are satellite altitude, attitude, projection differences from a planar to a spherical system, and Earth rotation.

3.3 Enhancement

Enhancement has as its main objective the task of satisfying the peculiarities and dynamic capabilities of the human observer. Enhancement techniques are basically oriented to an improved display or to accentuate the visual appearance based on a model of human perception. Enhancement techniques basically do not contribute to radiometric accuracy. They can cause geometric inaccuracy when the technique causes a pixel to be classified in the surround as opposed to the target or vice versa.

The enhancement techniques discussed in Section 5.3 essentially modify the image feature based on a subjective model of how a target should appear.

Most of the enhancement techniques entail stretching of the data to improve the dynamic range and filtering such as high/low pass and medium filters. The high pass filters restore edges or structural detail that are lost due to inaccurate or inadequate sampling by the sensor (see Figure 6). The high pass filter then restores high frequencies that were altered in the imaging system. One drawback to this method is that it tends to depress low frequency information while it amplifies the high frequencies. This is called edge enhancement. Low pass filters preserve and enhance low frequency information. An example of a low pass filter is:

$$F(x,y) = \begin{cases} 1 & \text{for } \sqrt{x^2+y^2} \leq R \\ 0 & \text{otherwise} \end{cases}$$

where R is a threshold value. The medium filter is used to remove noise without degradation or smoothing of edges.

Removal of radiometric striping is another area where enhancement techniques are used. The most effective method is to do a fourier transform of the image, identify the concentration of energy due to striping, set the intensity components to zero, and retransform to the image domain. In summary, basic image enhancement processes are concerned with the following areas:

1. Noise suppression
2. Removal of distortions
3. Resolution enhancement

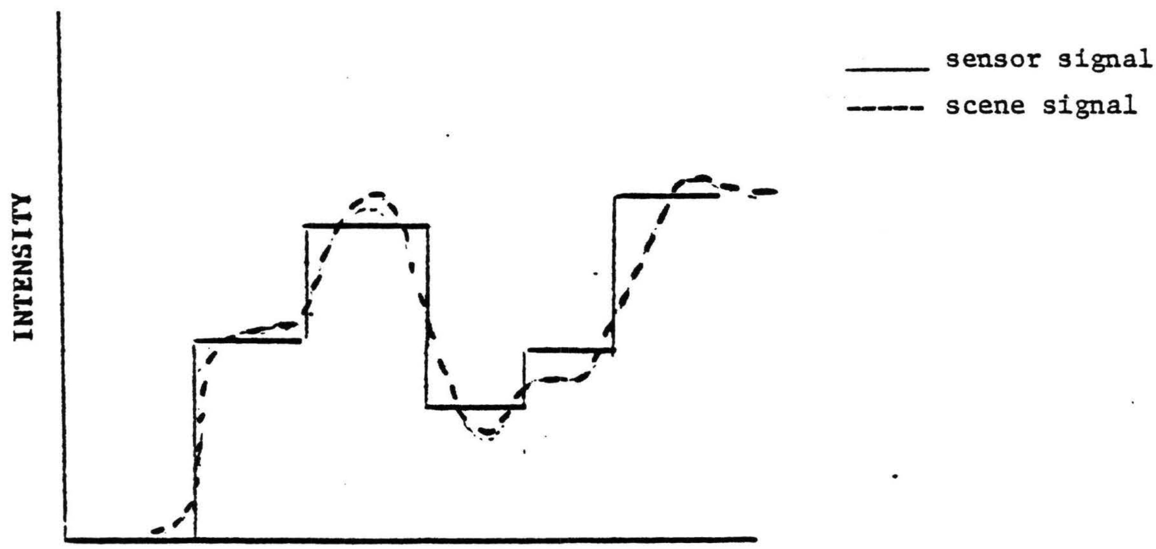

Figure 6. Modification of scene due to sensor quantization

4. Contrast enhancement
5. Contour enhancement
6. Image blending

3.4 Hardware/Graphics

The hardware and display characteristics of data have been covered above in Section 1.1. Included for completeness is a short discussion of graphics, as graphics is considered a subset or a technique of digital image processing. Some of the most interesting developments in the area of graphic display are the evolution of encoding in an image digital information such as elevation. Other typical graphics devices use gridded information added to the imagery.

3.5 Image Analysis or Pattern Recognition

This area is basically concerned with the classification and information extraction techniques. In Figure 7 is the way the scene or object of the sensor is broken down into classes at different levels. In order to differentiate to each level, it requires a certain increasing sophistication in either spatial, spectral, or temporal discrimination and increasing complexity of IP algorithms. The ability to differentiate the scene into a specific set of distinct classes is a capability of some sensors. However, IP algorithms do exist that can through either supervised or unsupervised techniques, classify different scene features. In terms of user requirements, it is usually identification and mensuration of different targets that are of utmost importance. In terms of IP algorithms, it is of paramount importance that the spatial, spectral, and temporal relationships be isolated. Whereas much work has been done in spectral evaluation, spatial and temporal techniques have not been developed thoroughly. The problem here is that spatial techniques that separate or classify targets

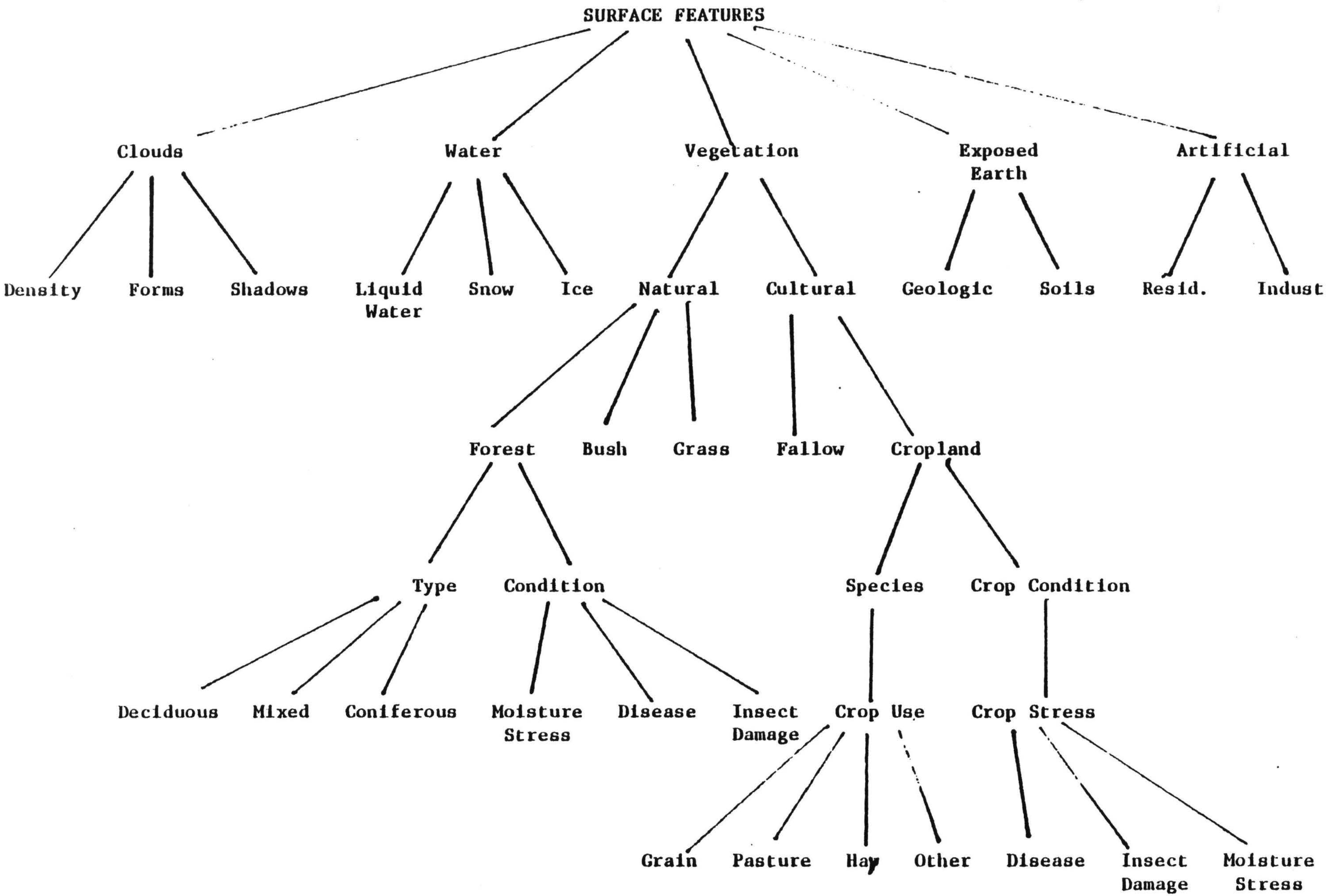

Figure 7. Analysis information system

by areal extent are very time consuming for computers (Kirlin, 1980). Temporal techniques have also not received the development that is required to make them profitable for pattern recognition. Lack of data availability has hampered development of temporal techniques. Another temporal problem is calibration and registration differences that create uncertainty in the absence of repetitive data sets. Since cloud cover limits repetitiveness, temporal techniques have not been adequately developed.

4.0 Overview of On-going IP Activities at Various Institutions

The facilities at CCRS, USC Image Processing Institute, and the GEOBASE INFORMATION SYSTEM STUDY GROUP are all active in image processing activities. Reports (see Bibliography) have been generated that discuss their current activities and outline their future image processing objectives. These objectives are summarized below.

4.1 IP Activities that are of importance to CCRS are as follows:

1. Develop an on-line quick-look facility for imagery with remote inquiry stations at regional applications assistance facilities. The data from CCRS will be stored or staged to a digital data system that will transmit imagery via ANIK-B to remote facilities. There will also be some communications via land lines with other facilities.
2. Develop a data base or procedure for area selectable imagery. This activity implies a generalized mosaicking capability.
3. Develop variable haze map methods for each scene.

4. Utilize 70x70 m imagery and develop ground control point criteria so that 10-20 m location accuracy is achievable.
5. Investigate requirements from other Earth resources systems other than Landsat and develop ground processing systems when a need is demonstrated.

4.2 Santa Barbara Conference

The Santa Barbara Conference on GEOBASE information systems (April, 1978) made the following recommendations concerning development of image processing algorithms:

1. Evaluate polygonal versus cellular data bases for remote sensing data. Evaluate the use of gridded information.
2. Document the effects of bi-resampling on classifier performance for cultural and non-cultural imagery.
3. Develop projection transformations and identify the error associated with the different cartographic projections. Development of inter-conversion techniques for reformatting data from image to map space.
4. Develop a set of "standard" statistics by path/row and calibrate each path so that radiometry does not vary from scene to scene.
5. Investigate radiometric and geometric calibration and feathering techniques where scene overlap occurs.
6. Evaluate data compression techniques for archival and transmission purposes. These techniques should be reversible to system noise level.

7. Develop cloud cover estimation techniques which would include spatial distribution of cloud cover.
8. Develop the capability for area selectable imagery and "universal" mosaics.
9. Investigate and document data communication of imagery via spacecraft and/or land lines.

4.3 USC Image Processing Institute

The following areas are currently being investigated for thesis material at the Image Processing Institute at USC:

1. Quantitative measures of image quality.
2. "Blind" and non-linear restoration techniques.
3. Development of noise models for image restoration.
4. Figure of merit for boundary detection and edge enhancement algorithms.
5. Symbolic image encoding.
6. Generalized brightness corrections for mosaicked imagery.

4.4 IP Development at EDC: Basic Requirements

The Systems Development Branch was requested to identify the IP activities that should be pursued over the next 2-3 years. In order to identify these activities, it is first important to define the products needed over the next 2-3 years and then identify those IP techniques required to provide those identified products. It is proposed that generalized techniques be used to support many areas at once instead of developing many product unique techniques for purposes of economy. It is also felt it would be useful to identify both near and long-term product lines. A very important additional consideration is what products and techniques could be developed to satisfy repeatability requirements.

Lastly, it is important to identify those products requiring special versus pipeline techniques or those having an interactive versus batch flavor.

The areas of product development which were felt important in terms of priorities listed above with the required techniques are as follows:

1. Geologic/Geographical Analysis
   a. Non-cultural products
      - Edge enhancement techniques
      - Mosaicking
      - Stereo and radar data
   b. Cultural Products
      - Mosaicking
      - Improved spatial resolution
      - GCP and/or RCP activity
      - Area selectable data
2. Vegetative Analysis
   - Ratio technique
   - Brightness masking
   - True color (TM)
   - Better spectral and spatial resolution

3. Shallow Seas Analysis

- Radiometric techniques for improved display of sub-surface and surface phenomena
- Low radiance areas of high interest, therefore, noise removal techniques
- True color (natural or false color w/TM)
- Oil exploration and improved spatial and spectral resolution
- Emphasis on radiometric technique improvement

4. Meterological Analysis

- Snow melt
- Environmental damage assessment
- Quick-look facility and on-line data bases to improve data timeliness.

In order to evaluate the impact of algorithm development on products over the next 2-3 years, it is important to define algorithm research and development activities as well as new hardware and sensor developments.

4.5 IP Algorithm Development at EDC

Areas that seem optimum for algorithm development at EDC are:

1. Projection driver techniques: To produce mosaics and area selectable imagery expertise in feathering of overlap areas (this is a blending technique), surface filter for variable image sizes, and generalized brightness guidelines need to be developed.

2. Formatting of data: Determining optimal data structures for feeding CRT, film and tape formats for a variable product line. This approach might also include symbolic encoding techniques for transfer of information.
3. Ground control point library development for fitting of image data. Improvement of spatial resolution will drive the development of more accurate Earth location techniques of the data. The Stereosat development is assuming that corrections for platform and ephemeris will be so accurate that GCP's will not be necessary. However, in most of the world, the accuracy of the maps is not sufficient to support GCP. In this event, relative control points (RCP's) will have to be developed.
4. Interpolation techniques: Develop techniques to optimally restore resolution (spatial and spectral) and to take advantage of over-sampling characteristics.
5. Blending of image data with non-image data. Digital terrain with MSS data for improved classification (Bauer, 1980).
6. Ratio images: For vegetative vigor and stress detection as well as water depth mapping.
7. Brightness masked hue images: For detection of subtle terrain color differences.
8. High and low pass filter techniques: High pass for lineament detection and low pass for identifying target of a low frequency nature such as submerged objects.

9. Spatial filtering techniques: For improved classification in that adjacent pixels have a high probability of belonging to the same class.

4.6 Summary of On-going IP Algorithm Development

Advances and applications of new sensors such as the MLA and smart sensors as well as better spectral and spatial resolution, will drive many of the developments in IP algorithms. Smart sensors, which integrate the sensing device with a processor on a chip, will transfer some IP function to the satellite. Of course, the old problem of users who want processed versus raw data will continue to plague the ground systems manager. Additional smart sensor developments are planned for the 80's where all or most of the present ground processing is done aboard the satellite. This would include techniques where sensed information for an area is checked against a data base for that area. If new information has been sensed, then it is down-linked, otherwise the data is dumped. The basic reason for this development will be the increase in data rates.

Also, changes in the Data Center itself will affect IP development. If hardware integration of the major main frames occurs, then certain IP activities will develop faster. For example, if the EDIPS could be used as both a pipeline system to Computer Services Branch and an IDIMS like development system to whoever, more IP functions might be in an output product mix.

5.0 Future Image Processing Algorithm Developments

5.1 Coding and Techniques

Among the areas where the most intensive algorithm development has occurred is in bandwidth compression techniques. Most of the data compression algorithms being developed today, however, do not seem capable of keeping up with the increased data flow forecast for the late 1980's. For these reasons, mass store systems or a hardware solution is still envisioned as the most promising solution for the quantity of data. Along with this technique is the concept of gross information first or symbolic image encoding. This technique envisions that gross detail can be summarized before being transmitted to remote sites. What is considered here is that remote sites will interrogate a data base and gross or statistical information will be passed to the user before he orders or accesses the information. The data would be low resolution for this quick-look information.

Another area of encoding is the creation of data-base design to effectively store data in appropriate forms for retrieval and display purposes. Creation of a standard set of sensor data bases for measurement of algorithm improvement could also be implemented to solve problems of standardization. In a related topic to optimal data-base design, is image segmentation and the creation of what has been identified at EDC as selectible computer compatible tapes. Related to this is the optimal projection for various imagery and satellite platforms. The space oblique mercator (SOM) has been recommended to replace the Hotine oblique mercator (HOM). Projection on a globe is the ideal since the Earth can be modeled rather ideally as an ellipsoid. When two-dimensional projection is required, various algorithms for the projection are utilized. Algorithm development in this area will continue to seek ways to:

1. Minimize scale distortion
2. Produce conformality
3. Preserve continuity at all latitudes

4. Compensate for Earth rotation at higher latitudes
5. Have zones with larger coverage

Once an accurate projection method is available, it is not inconceivable to put bench-mark data at the end of an image file so that investigators will have ready made methods to Earth locate the imagery.

5.2 Restoration

Development of quantitative measures of image quality will continue to be a high priority in algorithm development. Figures of merit for various restoration are of great importance in providing measures of improvement. Another area of intense research is "blind" and non-linear restoration techniques. Greater use of scene statistics, for example, such as replacing the density values in band 5 of the multi-spectral scanner with its standard deviation so that one has a ready-made measure of texture channel is one way to use the present data in a statistically more meaningful way.

Development of better noise models for restoration purposes will still be required. Even though sensors with higher SNR will be on-line in the 1980's, increased resolution will still cause many problems. Increasing interest in the problems of multiplicative noise models is an area of active research.

Another area of restoration that is receiving a lot of interest is interpolation. Mostly those techniques that are now considered inefficient for present throughput requirements will be utilized more in the future because of improvements in hardware speed. Especially developments in parallel or horizontal programming will speed the implementation of techniques already developed but too time consuming. Also, since over-sampling is used to improve SNR and resolution, new interpolation techniques will be developed to take advantage of oversampling.

In addition to the above, as far as future work on interpolation is concerned, there are a number of important developments to investigate. Some of these areas to be investigated are:

1. Because resampling results in an increase of the point spread function, thus a decrease in resolution, what is the effect of bi-resampling and what are the optimal resampling techniques for input to the bi-resampling process?
2. Create context dependent interpolators that function on local scene characteristics as opposed to global techniques now used.
3. Develop interpolation techniques that are shape preserving techniques. Presently, the histogram changes very little as a function of shape of interpolator, however, boundaries of objects in the scene do change.
4. What sort of patterns are added to images as a result of resampling? That is, develop a figure of merit for resampling that measures the statistical effect.
5. Quantify the effects of bi-resampling.
6. The effect of bi-resampling on bi-resampled data.

5.3 Enhancement

Figure of merit for boundary detection and edge enhancement algorithms are important areas for developing IP contributions to image understanding. More spatial enhancement algorithms will be possible in specialized IP hardware environments of the future. Most of the techniques are scene dependent. However, new methods will be developed as the analyst develops a better concept of the underlying structure of the image. There are specific techniques which work quite well for specific problems. However, general techniques of edge enhancement do not exist that utilize scene statistics to determine what kernel size and/or filter to utilize.

Since more and better mosaicking capability will be developed, more rigor will be required to develop generalized brightness corrections for multiple overlapping imagery.

Another method of analysis that should produce better results is greater use of spectral and spatial filtering techniques. Better noise reduction will be possible as generalized Kalman filtering becomes available. If coded in array processors, most of the IP algorithms will be more useful and applicable to the small system user. Because of the speed of the AP, there will be better utilization of the small system.

5.4 Pattern Recognition and Image Analysis

Data integration techniques or correlation of an image with non-image data will continue to be important for algorithm development. Along with integration are problems of optimal resolution, registration, and the techniques of interpolation for missing data points. Also, optimal map projection for integrated data will spur more work in this area. Other areas of spatial data integration necessary to support the image analyst are given below. The following characteristics of spatial data must be considered:

1. Data format and archival media
2. Resolution, projection, and coordinate system
3. Observational criteria or how the data is grouped and whether or not it includes interpretative measures

4. Accuracy of data

5. Characteristics of sensor, satellite, and atmospheric path of collected data

Algorithms to take care of the above five points are in great need. Developing them will necessarily be a rather complex task. In addition, some measure must be taken of which tasks should be automated versus those which should remain as manual tasks.

Application of time series techniques will also be an area of development for classification purposes. Adaptive filters based on two-dimensional auto-regressive moving average (ARMA) processes are being developed to create classifications from resultant covariance matrices.

As more and more spatial algorithms are available on processors, topologically oriented algorithms will be available to evaluate connectivity of spectral areas as well as consecutivity of the various targets in a scene.

6.0 Summary

The development of IP algorithms over the next few years will address many of the same problems seen in the last 10 years (McMurtry, 1980). The fundamental reason for IP development is to improve the ability to extract information from data. In the past and the future, algorithm development will key on spectral, spatial, and temporal variations. Hardware evolutions as is stated above will pace many of the new developments in IP. More time is being spent on developing the software capability of present array processors. At the low throughput end, the development of the FPS 100 will put IP capability at the small user level. At the other end of the spectrum, the massive parallel processor that Goodyear is building for NASA/GSFC will see a larger capability for the data rates of Landsat D and the OERS systems to follow.

Even with all the improvements in sensors and ground processing most errors in IP algorithm are due to the fact that the algorithm makes an assumption about the scene that on closer inspection is not quite valid. Most IP algorithm errors are due to misunderstanding of scene components. Also, most of the algorithm development is related to PR techniques and no one is actively doing fundamental research. Most researchers are too busy doing applications. In separating the scene into components for identification, it is important that:

1. List of classes must be complete
2. Classes must have information value
3. Classes must be separable

What the user needs from the algorithm is to be able to recognize a scene component and measure its extent. These objectives will remain the same for the foreseeable future. Since there will be more and more spectral bands of different extent on future satellites, it will be necessary to understand relations between spectral classes in a much more sophisticated manner. Also, utilizing second and third order statistics in order to interpret the information in a band will be mandatory. It is in this area where the technique of principal components will be able to contribute a lot to our understanding. Principal components analysis yields a measure of correlation and dependence of various spectral bands or information channels.

Sensors such as MLA will characterize variations in the scene in a new way. More spectral channels will enable classifiers to advance further into the information tree of Figure 7. Better analysis of spatial variation will be available with increased resolution (10-20 m). Classification accuracy won't improve greatly over the present results due to resolution alone (Landgrebe, 1976). More class separability will probably occur, however. Current classification algorithms do not rely that much on spatial structure as they do on spectral value. Also, improvements in spatial sampling will occur due to Geostationary Earth Resources Satellites or more polar orbiting Landsat-type satellites.

Temporal variations will be evaluated as data sets become more complete. Essentially a good measure of what a target, such as crops, is can be identified if we can track its stages of development.

6.1 Conclusion

In conclusion, it has been demonstrated that some matching between the complexity of the data and the complexity of the algorithm will occur as the spatial, spectral, and temporal characteristics of satellite-borne sensors are improved. The data will be more complex because of the increased number of spectral bands, greater SNR, better spatial resolution, access to scene matching ancillary data, and the availability of multi-temporal data sets.

The requirements for future algorithm development will generally follow those outlined above. In support of these requirements, IP algorithm technique development will occur along these paths:

1. Increase of spatially oriented algorithms.
2. Algorithms which will make use of temporal variations such as time series analysis.
3. Conditional classification algorithms that optimize discrimination in the feature set.

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