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DATA MANAGEMENT TECHNIQUES FOR SPACE APPLICATIONS

Contract No. NASr-65 (25)

Final Report-Task 2

Technical Memorandum - 29

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IIT RESEARCH INSTITUTE

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DATA MANAGEMENT TECHNIQUES FOR SPACE APPLICATIONS

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SUMMARY

A study was conducted of processing, analysis and archiving problems associated with data from spacecraft sensors utilized for Space Applications. The objective was to determine possible sensor and instrumentation modifications for improving data management, for minimizing data-transmission requirements, and for making the data more useful. The emphasis was upon defining areas of promising technology developments rather than upon offering solutions to data-processing problems.

After describing the functions comprising the various data phases, current procedures were examined for processing data from three specific sensor systems: the Advanced Vidicon Camera System (AVCS), the High-Resolution Infrared Radiometer (HRIR), and the Medium-Resolution Infrared Radiometer (MRIR). While the three sensors are different in concept and operate in different parts of the electromagnetic spectrum, it was found that there is a striking similarity among the data phases. Presentation of results necessitates a major computation effort. For example, a large computer complex is operated four hours per day solely for the processing of global image data.

It was determined that for the present and proposed sensors, a commonality existed relative to data functions and data formats. Thus, a generalized analysis proved feasible. Functionally, the measurements made by the spacecraft sensors are integrated with information from three other sources: non-spacecraft data (e.g. spectral signatures), theoretical models, and environmental data. These are manipulated in a computer system to produce thematic "maps" or other presentations. Classification of instrumentation by imagers, spectrometers, transponders, and counters proved to be of more value than grouping by sensor application or by wavelength. The outputs are customarily arranged into three types of formats: image, contour, or digital. Techniques for generating these displays are within the state-of-the-art. Based on this examination of ground data-management procedures, possible on-board processing techniques and devices were described.

A data archiving and spacecraft annotation concept was devised which would improve both the data processing and the data archiving. The search and retrieval could be expedited through the use of four indices: flight designation, area sensed, specific sensor designation, and application. Since fixed descriptive information can be made available in the index file system, only the variable parameters need be recorded in the spacecraft. From the list of eleven variables it was concluded that the most significant were the time and pacing markers which tie the sensors to the surface element.

A number of recommendations were made. Increased attention should be given to on-board annotation of sensor data. Such annotation, plus on-board position identification, would greatly expedite ground data-handling and archiving. A study should be made of the applicability of a navigation computer, similar to that used in Apollo, for providing and inserting location and attitude data automatically. Further consideration should be given to more sophisticated programmers, integrated with environmental sensors, to optimize schedules for sensor operation. The new reversible-film technique should be reviewed to determine the resolution improvements of cameras compared with electronic devices. An investigation should be made of actual user requirements to determine the potential of encoding techniques. Using this method, only the key data need be transmitted instead of the entire sensor output. On-board spectral comparison would be complex and would require a large memory but it could greatly enhance the utility of the transmitted data. These types of instrument technology developments offer promise of achieving the objective of improved data handling.

I. INTRODUCTION

The purpose of this study was to investigate the acquisition, processing, analysis, and archiving problems associated with automated spacecraft systems. By examining the requirements for procedures, equipments, and organizational techniques, the objective was to determine how the annotated data could be made available to the users in a timely and equitable fashion. The concept of the study was to indicate where research resources might be allocated most usefully rather than to solve the data management problems.

After defining the data handling phases, the state-of-the-art is reviewed relative to processing data from television and infrared sensors. The commonality of the data handling is emphasized and some approaches to on-board processing described. Comments are made on a scheme for data annotation and data retrieval.

II. DATA MANAGEMENT PHASES

Sequentially, the data flow may be divided into on-board processing and processing on the ground. Since most of the processing is presently conducted on the ground, this aspect was further examined by grouping the steps into "Phases" as shown in the double boxes in Figure 1: Acquistion, Processing,

DATA-HANDLING FLOW PLAN

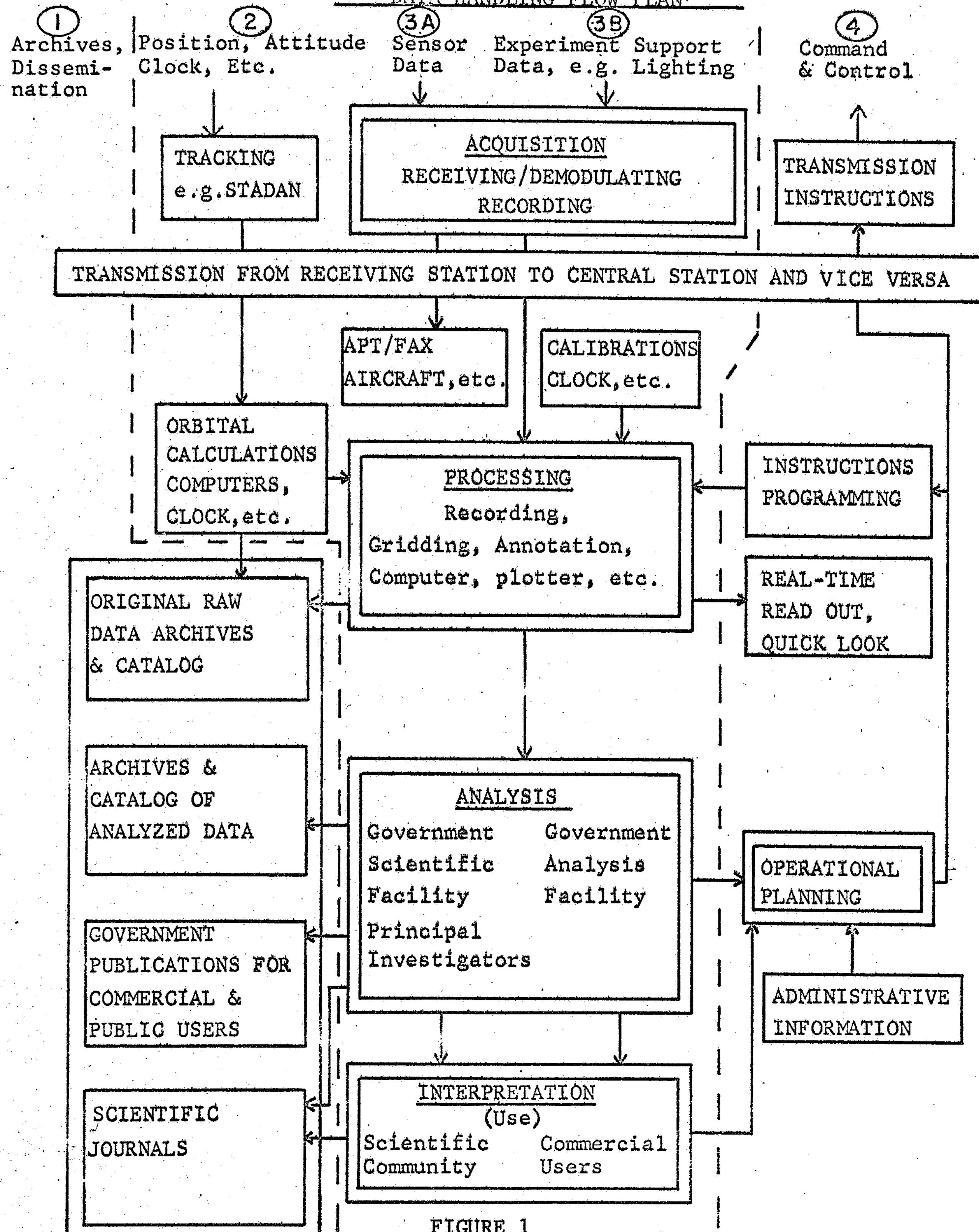

FIGURE 1

Analysis, Interpretation, Archives/Dissemination, Command and Control. The latter function was not investigated.

Most of the effort was devoted to consideration of the Processing, Analysis, and Archiving facets because these have the largest impact on the design of the spacecraft sensor systems. The Processing Phase is defined to include the initial steps of conversion (analog to digital), annotation, calibration, and display for quick look, as well as the more refined steps of smoothing, gridding, rectifying, and mosaicking.

The Data Analysis Phase is defined to cover two functions: comparison of data and preparation of thematic "maps" or graphical presentations. The comparison function was generalized to include examination of spectral signatures, "ground-truth" data, data from other sensors (synergistic or multi-spectral), prior data from the same sensor, and historical records. The presentation function related to the preparation of cloud cover maps, meteorological "maps" (inversions), thermal maps, demographic maps, topographic maps, etc.

III. TELEVISION AND INFRARED DATA PROCESSING

A review was made of current procedures for processing data from Nimbus and ESSA satellites at NASA-Goddard Space Flight Center and at the National Environmental Satellite Center. The various steps in the Data Processing Phase are listed in Figure 2 for the Advanced Vidicon Camera System (AVCS), the High-Resolution Infrared Radiometer (HRIR), and for the Medium-Resolution Infrared Radiometer (MRIR). The applicable Data Analysis Phase steps are listed in Figure 3.

Even though the three sensors are different in concept and operate in different parts of the electromagnetic spectrum, there is a striking similarity among the data management paths. This is shown by the asterisks in Figures 2 and 3. While the hardware and software are not exactly alike, basically all three data reduction systems are concerned with the location of the measured sensor data with respect to space and time. For any type of analysis of the sensor data it is essential that the position of the reduced data be located, whether it be by gridding and annotating on a film or photograph, or by performing the expedient act of merging orbital, attitude, and time information with reduced data on magnetic tape.

It is apparent that a large computer complex is required for the Processing and Analysis Phases. The Control Data Corporation Model 6600 computer is being used more than four hours per day for the processing of present-day resolution global image data. Future imaging sensors will have an even larger bit rate than the 6.6 million 7-bit bytes listed in Figure 2 for the AVCS. On the other hand, some of the future sensors may have a lesser computer processing requirement: To reduce a day's volume of Satellite Infrared Spectrometer data,

SENSOR DATA ANALYSIS COMPARISON CHART

	Advanced Vidicon Camera System	High-Resolution Infra-Red	Medium Resolution Infra-Red
1. Meteorological Digitalizes Data Tapes (Binary) (Merged Telemetry, Altitude, Orbital, Sensor	*	*	*
2. Computer Listings of Selected Temperature Data		*	*
3. Computerized Data Retrieval System (SIP)	*	*	**
4. Output Formats (Types)	*	*	*
a) Images with varying grey scales	*	*	*
b) Temperature contour map		*	*
c) Digital (numerical print of parameters)		*	
d) Vertical temperature, Botach profiles		*	
e) Compositional analysis (CO_2, H_2O)		*	*
f) Non-meteorological data(ice, snow, ocean currents)	*	*	*
5. Frequency/Coverage	*		
a) Complete global	*	Orbits Leave Gaps	
b) Report daily	*	Aperiodic	

FIGURE 3

which would produce several thousand indirect temperature versus altitude soundings through a mathematical transform equation, it is estimated that only several minutes would be needed using the CDC 6600.

Certain questions may be raised concerning the trend of future computer processing for these type data. Should the emphasis be placed on larger, faster, and more expensive computers than the CDC 6600 or should the emphasis be directed to small general purpose computers or to specially-built computers? Should more of the annotation and gridding operations be transferred to the spacecraft to by-pass much of the ground processing? It is believed that research resources should be directed to the latter problem to assist in answering the prior question.

IV. COMMONALITY OF DATA MANAGEMENT

A. Functional Commonality

Based upon the analysis of current data management procedures and upon an examination of the type of activity expected from future sensors, it was determined that the fundamental data processing functions are very similar. As shown in Figure 4, the measurements made by the spacecraft sensors are integrated with three other data sources: some "ground-truth" signatures or spectra, some form of a model to aid in

CONCEPT OF DATA-HANDLING FUNCTIONS

FOR ADVANCED, MULTI-SPECTRAL SENSORS

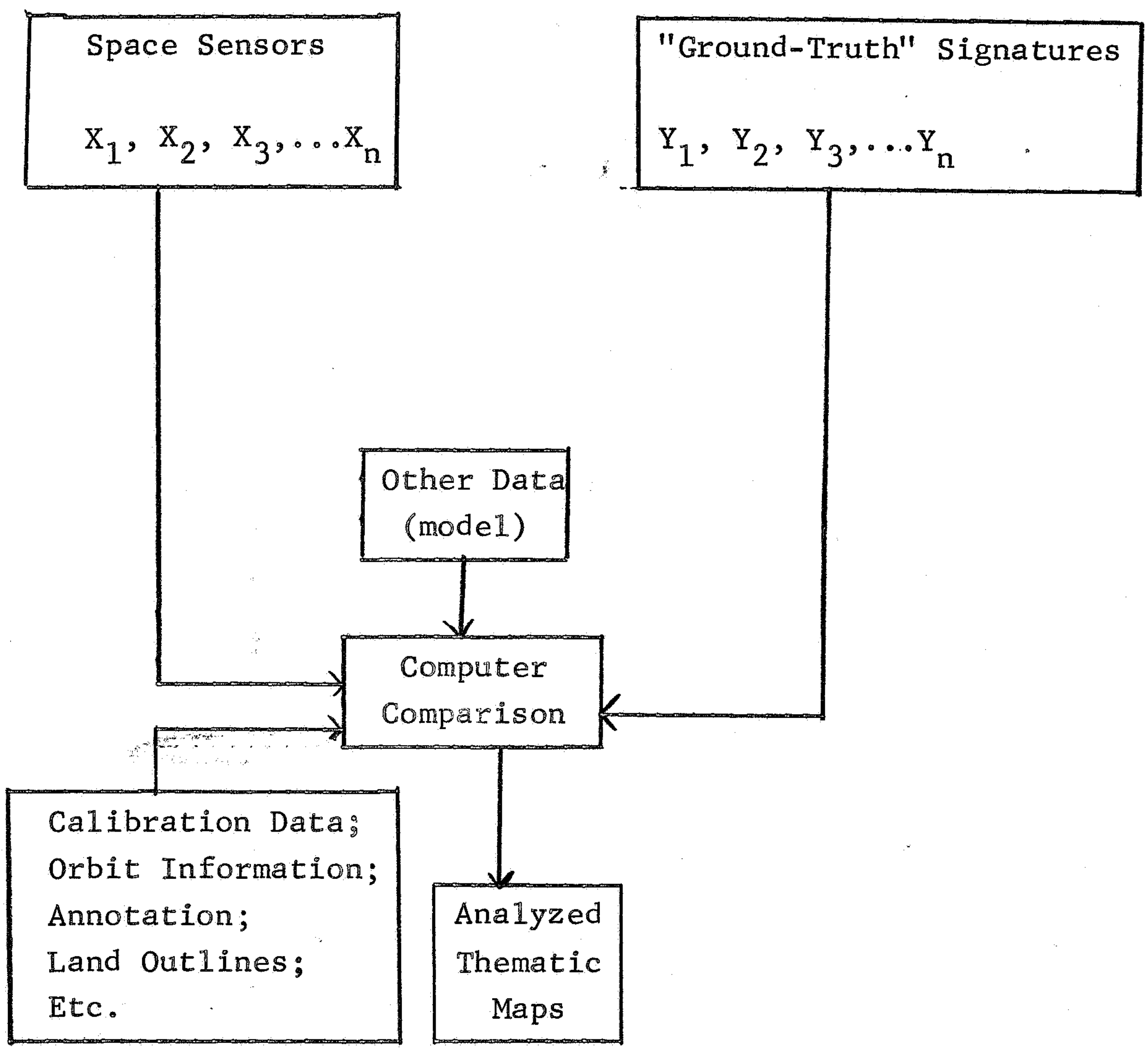

FIGURE 4

interpretation, and some environmental data relating to space/time factors. These are manipulated in a computer system to produce various types of presentations or "thematic" maps (picto-grams). In order for the sensor data to be most useful, it is essential that either progress should be made in the other three inputs to the computation or the sensors should be modified to be more compatible.

Another way of considering the data function commonality is shown in Figure 5. Here the type of processes which are required for four types of sensors are indicated. It was determined that this classification of sensors (imagers, spectrometers, transponders, counters) was of more value for data management studies than classifications by sensor application (meteorology, hydrology, etc.) or by electromagnetic spectrum (visible, infrared, microwave, etc.). In other words, the data processing is relatively independent of the user and the wavelength. The double asterisks indicate that, for imagers, the greatest complexity occurs in the Data Processing Phase while for spectrometers, the greatest complexity is in the Data Analysis Phase, particularly the interface with the model and the spectral signatures library.

B. Output Commonality

After reviewing the types of outputs from the data processing of sensor data for various space applications, it

DATA MANAGEMENT

FUNCTION COMMONALITY CHART

DATA HANDLING FUNCTION	SENSOR TYPE			
	IMAGER	SPECT-ROMETER	TRANS-PONDER	COUNTER
I. Data Processing				
Analog/Digital Conversion	*			
Calibration	*	**	*	*
Overlays and Gridding	**	*	*	*
Rectification	**			
Mosaicking and Projection	**			
II. Data Analysis				
Measurement	*	**	*	**
Conversion & Inversion				
Comparison				
Spacecraft Sensors	*	**		*
Comparison				
Other Data	**	**	*	*
Presentation & Display	**	*		*
III. Data Interpretation				
Forecasts	*	*	*	*

FIGURE 5

became apparent that the end product may be considered to be of two classes: "maps", or "soundings". The former class emphasizes the topographic aspects where the x,y, coordinates are latitude and longitude with some indicator, z, plotted to show the global variation of the measured parameter. The latter emphasizes the altitude above the earth's surface to show vertical profile effects.

The actual thematic map output may seem radically different. For example, a cloud picture from the AVCS seems far removed from a surface thermal contour map derived from IR sensor readings in an aircraft. However, this is only a difference in display format. From the point of view of data management it makes little difference what the measured parameter was, but it is considered to be of three categories: image, contour, or digital. The image format is like a picture the eye would see from space, either in tones of grey or in color, i.e. the APT/AVCS television pictures or the Gemini camera pictures. The images also could have been obtained in the non-visible part of the spectrum and be computer-generated as a representation of certain phenomena. While there may be great differences in either levels of grey or size of the resolution elements, the format is the same. For example, the HRIR images look smooth while the recent "pictures" developed from microwave sensors are coarse. These microwave images are obtained from aircraft produced in several colors with resolution elements about 1/8 inch square in size corresponding to about an acre on the ground.

The contour format includes some analysis wherein a determination is made as to numerical values of some parameter. For illustration, thermal contours have been drawn on HRIR images to show currents. The digital format has the results presented in discrete intervals, such as a numerical print-out of HRIR temperatures on a Mercator projection.

These images may be produced in four ways: "directly" from the sensor (APT), manually (HRIR montages), by plotting machine (x,y plotter driven by a computer), or by computer (numerical values printed on a map). These display techniques are well in hand so that the selection of the approach can be based on user-preference.

The data management situation for the "soundings" class of output does not appear to be as well defined. Again, the concept is elementary: some characteristic parameter such as cloud-height, temperature/pressure/density or constituents (water vapor, ozone, CO_2) is derived from the measurements. The objective is to determine the variation as a function of altitude over the earth's surface. This class is predominantly for meteorological applications. As it introduces a fourth "dimension" (latitude, longitude, altitude, and the key parameter), it makes presentation more complicated. However, again from the point of view of data management, major innovations are not needed. For example, vertical cross-sections have been developed using HRIR data to show temperature, isotachs, and humidity. The vertical axis can be altitude or pressure and the horizontal axis can be latitude, e.g. along 140° E. longitude. The mathematical modeling and analysis to derive such a display is complex, but the data handling is not novel.

V. APPROACHES TO ON-BOARD PROCESSING

The potential for on-board data processing was examined with the objectives of reducing the transmission (bandwidth) requirements, reducing the ground-based data management complexity, and making the data of more value to the user. It appears that conventional analytical tools may be applied. Systems analysis and information theory may be employed to indicate possible improvements in sensors and instrumentation. Possible techniques and equipments were described but not evaluated.

A. Techniques

Some of the techniques which might be applicable include pattern recognition, encoding, reduction in redundancy, and sensor alignment. "Pattern recognition" was used in the generic sense to mean a comparison of sensed data with other data which may have been stored before launch, acquired in prior orbits, or obtained from other channels or sensors. The comparison may be on the basis of spectral analysis, such as crop identification, or geometrical overlays, such as cloud patterns. An alternate approach, which eliminates much of the memory and computational requirements in the satellite, would be to keep the sets of basic "pictures" on the ground. Using the larger transmission power available from earth stations, the series of pictures would be sent to the satellite for on-board comparison. Only differences would be retransmitted.

Other types of encoding might be considered so that only the pertinent part of the data acquired by the sensor need be transmitted. In order to reduce the bulk by encoding, it is necessary to determine useful characteristics of the data; perhaps employing only cloud outlines or only the areas in the clouds where there is precipitation or only cloud movement or turbulence. It may be that some users really require only the area, the centroid, and the first moment (shape) of the presentation. The potential advantages of encoding may be lost if there are multiple users for the same sensor data. For example, if a series of encoding programs are required, it might be wiser to transmit the entire sensor content and break it down on the ground.

The reduction in redundancy could be obtained in a variety of ways. Initial selection of the sensor swath width, orbital altitude, and observation times regulates the basic overlap across the ground track and along the track. A controller can be programmed to minimize the overlap. At the poles, for example, it may select only every nth orbit for activation. In addition, on command the coverage pattern may be changed as in the case of the ATS where the spin-scan camera can survey the entire hemisphere in about 20 minutes or a lesser area more frequently. When an area has been adequately mapped, the programmer could automatically switch to another area. Alternatively, sampling procedures could be employed over areas that do not have to be completely surveyed. The choice of the representative sub-areas would be made after good initial coverage. Thus, by changing the areal and the temporal observation scheme, the amount of initially acquired data could be reduced.

Sensor alignment could be considered in the broad sense covering registration and indexing. This is necessary so data from various sensors or detectors in the same instrument subsystem (e.g. a 3-tube TV) can be correlated. A sensor integration problem of insuring an optimum match of field-of-view, resolution and altitude for combinations of sensors may be present. In a prior study, related to experiments for the Apollo Applications Program*, IITRI recommended that the fields of view of the metric camera, the side-looking radar, and the wide-range IR scanner can be modified for compatibility. Se-

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*Bock, P., "Experiment Profile Analysis for the Apollo Application Program APP-B Mission," IITRI Technical Memorandum - 24, January 1968, p.5.

lection criteria would have to be developed.

The possibility of rejecting "bad" data at the source should be examined. At times the bad data can be easily recognized, perhaps as equipment noise or spurious signals. Wrong exposures might be susceptible to automatic rejection. Natural interference phenomena, e.g. rain or clouds may also modify sensor operation. In between the obviously bad data and the noticeably good data is a class of data which must be subjectively analyzed to determine its value. As time passes the amount of data falling into this class might be reduced through expanded application of automatic analysis techniques.

B. Equipments

More sophisticated command programmers could be employed to improve the acquisition and transmission of useful data. The programmers could receive inputs from other devices to better select the times of observation. For example, a sun-angle sensor and/or an illumination measuring device could control the cameras and infrared sensors. Another input to the programmer could be a "cloud" sensor which would activate the sensor only when there is a clear view of the earth's surface.

Other techniques and equipments might also be employed to minimize the adverse effects of clouds. Beside the concept of a cloud sensor, the detectors could be programmed for each orbit by command based on weather predictions. Another scheme is to employ gimballing so that the sensors could be aimed at holes in the cloud cover. Gimballing also would greatly reduce the attitude control fuel requirements if any off-nadir observations are to be made.

Another major innovation would be the utilization of state-of-the-art computers. Adaptation of a computer such as that used in Apollo would provide the excellent navigation and attitude data which are required for data interpretation. The need for post-observation insertion of tracking data would thus be greatly reduced or eliminated. The computer also would be useful for the areal and temporal selection techniques described above, e.g., the mapping priority could be inserted minimizing real-time commands. Of course the on-board computer would be essential for any of the "pattern recognition" concepts outlined above. It would be tied into a recorder and/or "film library" for this purpose. Computers presently being considered for the F4 and the F-106X aircraft appear to have performance in the class required for the spacecraft functions. Careful attention would have to be given to the associated peripheral equipment (e.g., displays) and software. Integrated data systems combining adaptive multimode sensors programmed and operated by a multiprocessor also may have promise.

On-board data processing will be improved as a result of progress being made in both tape and film recording. Using solid state devices, the tape recorder complexity can be shifted from the mechanical to the electronic sectors with an increase in reliability. Although there are many developmental problems remaining, advances in film state-of-the-art may overcome the film expenditure limitation. Kalvar is a reversible film which might be useable in a controlled environment. Alternatively, the photochromic materials or thermo plastic techniques may have potential.

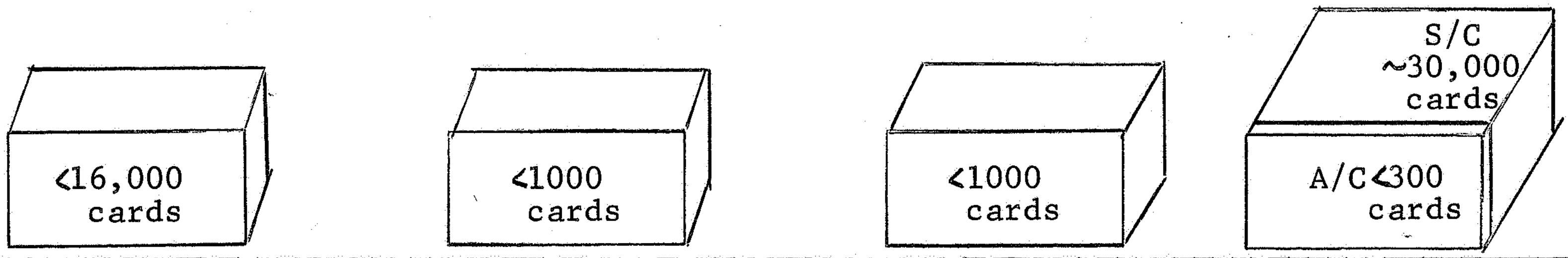
In examining two cases representing divergent on-board data processing requirements, it was concluded that on-board spectral comparison to produce global estimates of wheat production would be quite difficult to implement. On the other hand, techniques for on-board processing of sensor data relating to icebergs, currents, and wave height might be feasible.

VI. DATA RETRIEVAL AND ANNOTATION

A. Retrieval

As part of the on-board processing investigation, a data archiving and spacecraft scheme was devised which would improve both the data processing and the data archiving. The users were grouped into those most interested in the application, or in the instrumentation, or in both plus technical administration aspects. It appeared that the data search and retrieval could be expedited by using four indices: flight designation, area sensed, specific sensor designation, and application (Figure 6).

In identifying and requesting a specific set of data, it is only necessary to note the appropriate flight/area/sensor numbers (FAS) and the presence or absence of any associated "ground-truth" data. A prepared list can then be referred to which has identifying inventory roll numbers that have been assigned to each roll of data gathered under a given FAS code; this provides an indication of data bulk to the search as well as uniquely accounting for those cases where a given FAS combination has generated more than one roll of data. Such an approach implies that the Data Facility store the data by FAS "bins" wherein each roll has its own identifying inventory roll number (also recorded periodically on the actual data strip) or a removal card showing where the roll can be located. Any available ground-measurement (calibration) data and pertinent reproductions of the actual flight log may also be stored on the same FAS basis. On request, the Data Facility could also make available the ground-track map of a given flight number generated by the on-board navigation computer or the ground tracking net. In effect, this ties in all sources of information related to a specific set of data that is retrievable by a system such as that suggested in this section.



Flight Designation File Entries:	Sensor Designation File Entries:	Application File Entries:	Area/Grid File Entries:
1. Flight #, i.e.,F-1.. 2. Cognizant contact 3. Date-stop/start time 4. Vehicle(nomenclature) 5. Request altitude/speed 6. Area(s) by grid # a.#runs b.ground measurement c.Specific site #'s where applicable 7. Sensors (broad concept), #'s 8. Directed application, #'s	1. Sensor #, i.e., S-1. 2. Principal contact 3. Equivalent nomenclature/experiment title 4. Brief sensor description a.All fixed parameter values (λ, power,etc) b.Operation(qualitative) c.Kind of data, (tape/film,analog/digital etc.) 5. Flight #'s sensor present	1. Application #,i.e. T-1. 2.Cognizant contact 3.Brief definition of the application 4.Flight #'s Application directed Note: New application areas may be revealed after analysis/interp. This requires file up-dating	1.Area #(use in conjunction with AMS Map),i.e., A-1,... 2.Lat/long. of boundaries(useful redundancy) 3.Applications Test Site #'s assigned in this area 4.Flight #'s Area sensed a.Specific site #/location name,if sole objective of flight within area. b.Mapped ground track available as generated by some navigation computer plotted onboard

FIGURE 6 SUGGESTED DATA RETRIEVAL FILE

A general principle emerges from this discussion. All fixed descriptive information should be made available to potential data searchers in the index file system selected. Only variable parameters need to be recorded on the actual data roll with one exception. Since the data roll may be cut up or only portions thereof are reproduced for transmittal to the requester, it is necessary to potentially record the identifying inventory roll number on the roll to establish the original source from which any portion came. This general principle is significant since recording space on the data roll may prove to be a serious limitation as the program develops.

B. On-Board Annotation

Having removed the need for recording most of the fixed (constant) experiment legend on the actual data (since this can be available from the data retrieval file), the information on the data roll is primarily restricted to significant variables. The latter have been divided into two groups. The first group contains those variables which will be commonly needed by all sensors, while the second is restricted to a specific sensor with its unique requirements. This division will be useful in the selection of on-board recording hardware and techniques since equipment commonality is a desirable objective.

For purposes of legibility and summarization of suggested on-board variables which will be commonaly needed by sensors,the following are offered: Roll identifier (inventory #); Latitude/longitude; Time-hr/min/sec; Internal pacing markers (masterclock references); Altitude; Velocity; Inclination; Yaw angle/rate; Pitch angle/rate; Roll angle/rate; Run #. Perhaps the most significant of these are the time and pacing markers which tie in all sensors for purposes of correlating data over the same specified element.

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