LARS Information Note 103168
Purdue University

SCANNER DATA SYSTEM DEFINITION STUDY

by
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A brief study was conducted to define the basic characteristics of a multispectral airborne scanner for use by research programs in remote sensing of earth resources. The data handling system/scanner system interface was studied and data handling factors influencing scanner design were considered. This note is intended as a record of what was done on the problem and does not attempt to specify a recommended system.

The elements in the data chain from scanner to research worker who uses the data are shown in Figure 1. The guidelines for the brief look at the problem were as follows:

I. Define System so that output of Scanner creates minimum A/D and reformating time and problems without increasing complexity of scanner operation or degrading image output. Start using the University of Michigan system with improvements.

II. Define how our current equipment could fit into this system. What changes in our equipment would have to be made? Are there changes in the above scanner which would have to be made to implement the system with our existing equipment?

Look forward as far as possible for required system operation with the constraint that this is a research system.

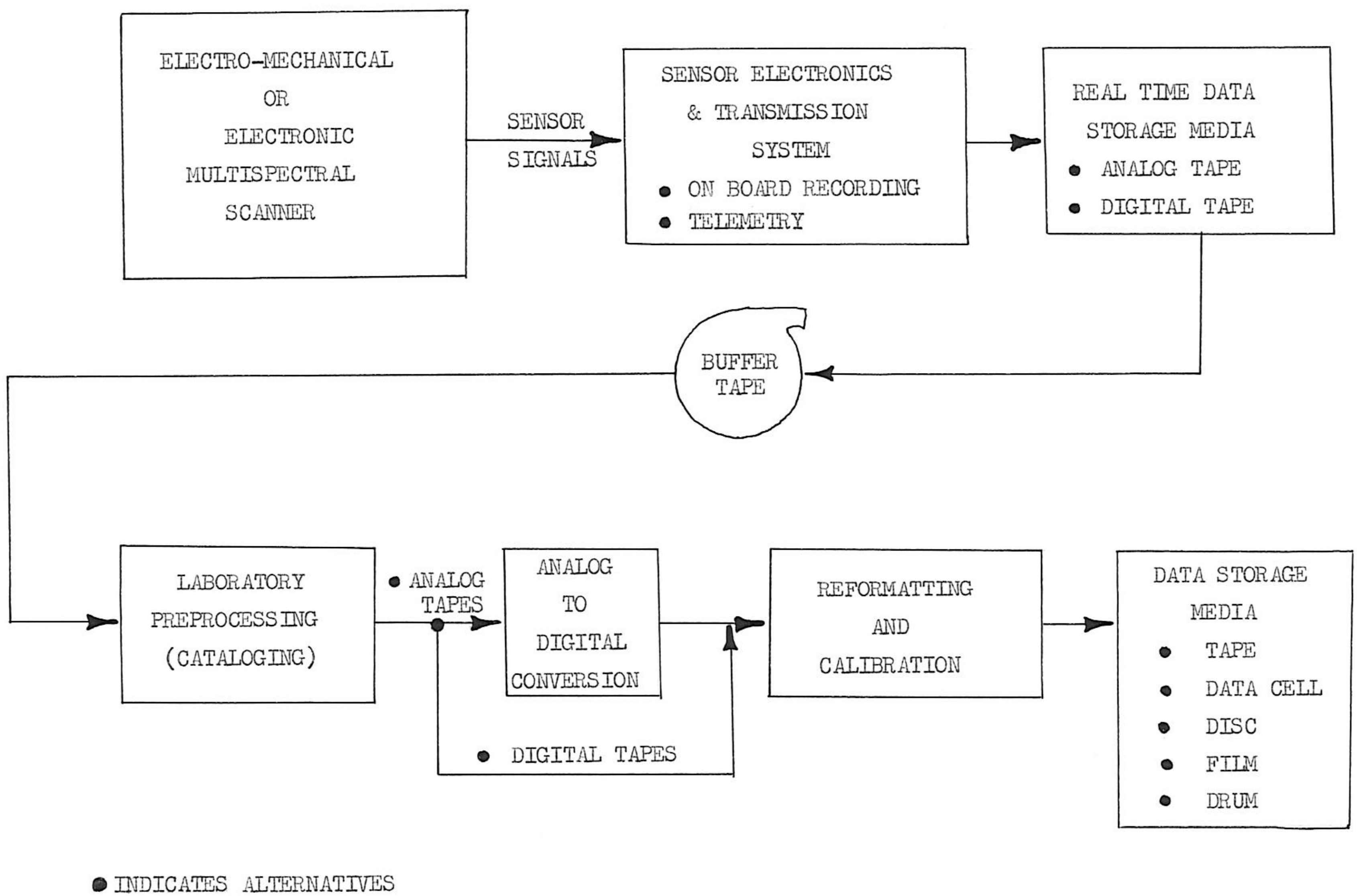

Figure 1 Scanner Data System Structure

III. Consider use of data storage tapes, i.e., pictorial outputs, LARSYSAA, D.D., etc.

IV. Consider other storage media, data cell, disk, etc.

The scanner system has two major defining characteristics:

1. Measurement Specifications - are the definitions of range, accuracy, stability, and frequency response which are necessary to produce the type of data desired by researchers.

2. Data Format Specifications - define the manner in which signals are sensed and delivered to the data handling system. These characteristics include analog or digital signal form, format (line scan, conical scan, etc.), and scanner platform.

Both of the characteristics influence data handling system design, however, No. 1 is input to the DHS design and No. 2 is influenced by feedback from the DH system considerations. System design can be considered a closed loop process as pictured in Figure 2. The design process starts with certain initial conditions which are ultimately determined by the agency funding the development effort. Two system initial conditions exist at the present time; 1.) The existing University of Michigan scanner characteristics would be the starting point for limited system improvements, 2.) The general purpose NASA scanner development. The measurement specifications assumed to be inputs to the look taken here are:

1. Number of Channels - 25
2. Wavelength Coverage - 0.3 to 14 microns
3. Resolution - 1 milliradian

4. Angular Field of View - 80 degrees
5. Continuous Calibration Required
6. Aircraft and Navigational Data must be sensed and recorded along with scanner data.
7. V/H Ratio - .2 to .02 rad/sec.

The problems considered are discussed below in the order they were attacked and not necessarily in the order of importance.

Data Rates

Consideration of the scanner data handling problem indicates that the basic problems found in the present system is signal form, that is, analog form. With analog representations of various quantities (data, calibration, time, aircraft altitude, etc.) a great deal of effort must be expended to get the information into stabilized, calibrated, digital form. The approach to improvement of this system aspect may be to realize that digital representation is desired and to design the system so that data is generated in digital and not analog form. Then the many detailed and costly A/D conversion steps would be eliminated and much of the digital processing would be eliminated.

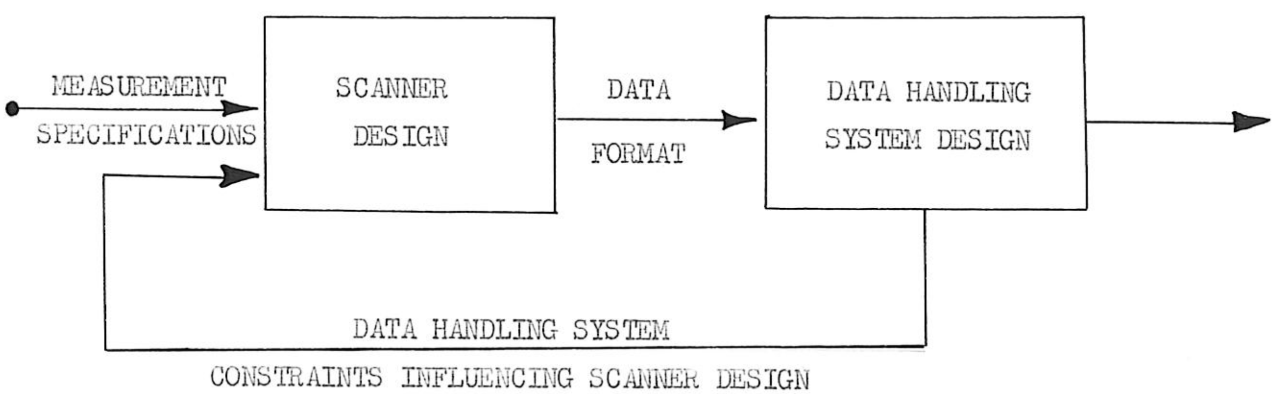

Figure 2 Scanner Design Loop

The first consideration which should be made is that of data rates:

Lateral Scan Line Type Scanner

Let $\dot{\theta}$ = Scanner angular rate (rev/sec)

$\Delta\psi$ = Angular resolution (rad)

NC = Number of channels

ψ = Angular field of view (rad)

M = Data accuracy (1 part in M)

The total number of bits per second of digital representation of the data for a given constant $\dot{\theta}$ is:

$$DR = \frac{\psi \dot{\theta} NC \log_2 M}{\Delta\psi} \text{ bits/sec}$$

For the present University of Michigan system the rate would be:

$\dot{\theta}$ = 60 rev/sec

$\Delta\psi$ = 10^{-3} rad

NC = 18

$\psi = 80^{\circ} \frac{2\pi}{360} = 1.4$ rad

M = 256

$$DR = \frac{1.4 \cdot 60 \cdot 18 \cdot \log_2 256}{10^{-3}} = 12.1 \times 10^6 \text{ bits/sec}$$

A more general evaluation for the data rate can be obtained by using sensor platform forward velocity and altitude as parameters and angular resolution as the independent variable. Other parameters are number of channels, angular field of view, and data word accuracy. The lateral side of the resolution element at nadir is $\sim \Delta\psi h$. In one revolution of the scanner optics (or one scan cycle) the craft moves forward Vt_s units of distance.

Thus the scan time is:

$$Vt_s = \Delta\psi h \text{ for square element (assumed)}$$

or

$$t_s = \frac{\Delta\psi h}{V}$$

$\Delta\psi$ = angular resolution (radians)

h = altitude in feet

V = velocity in feet/sec.

t_s = scanner cycle in sec.

The scanner produces one line of imagery each cycle. The number of samples per line is:

$$Ns = \psi/\Delta\psi \text{ (samples)}$$

$$SR = Ns/t_s \text{ (data sample rate)}$$

or

$$SR = \psi/\Delta\psi t_s$$

ψ = angular field of view (rad)

Ns = number of samples per line

If each sample is represented by an N bit ($N = \log_2 M$) sample then the data rate is:

$$DR = \frac{\log_2 M\ \psi}{(\Delta\psi)^2 (h/V)}$$

or

$$DR = \frac{(V/h)\psi \log_2 M}{(\Delta\psi)^2} \text{ bits/second/channel}$$

This expression will give the average rate per cycle. Since the scan line is created in usually less than a quarter of a cycle (i.e. 80°) for the single mirror University of Michigan configuration the actual peak bit rate out of the instrument is over four times greater than the average. Also reference and calibration data is usually gathered from sources within the scanner their extending the field of view with regard to data rate. The actual maximum data rate out of the instrument is:

$$NS = \psi/\Delta\psi \quad \text{samples/cycle}$$

$$SR = Ns/(t_s \cdot \frac{\psi}{2\pi})$$

or:

$$SR = \frac{2\pi}{\Delta\psi t_s}$$

and

$$DR = \frac{(V/h)2\pi \log_2 M}{(\Delta\psi)^2} \quad \text{samples/sec/chan}$$

Thus for the proposed NASA 25 channel system with 1×10^{-3} rad resolution with say a total ψ of 170° and a data resolution of 1024, the average data rate would be 45×10^6 bits/sec. and the peak is 95×10^6 bits/sec. for a V/h of .06. It is assumed that a buffering scheme would be employed which would produce the average rate out of the sensor system. Curves of data rate are drawn in Figure 3 for several values of (V/h) for a 1 channel sensor as a function of angular resolution. The table below gives some typical V/h values for likely aircraft.

Alt \ V	200 Mph	400 Mph	600 Mph
5000ft	.059	.118	.177
10000ft	.029	.059	.088
20000ft	.015	.029	.044

(V/h) VALUES

The data rate out of such a scanner would present severe problems in recording if the real time digital approach was followed. The recording rate for present 1600 bpi advanced units is 180,000 bytes or 1.44×10^6 bits per second. This capacity is far short of that required for the system outlined above. The analog recording technique presently has the capability to record one channel per track, these can handle a dozen or more channels whereas a digital unit could handle about one channel per tape. It will then be assumed that a wide band multiple-channel analog recorder will record the imagery on tape in any system in the near future.

Future operational systems may use on-board A/D, telemetry, and multiple ground based digital tape units for receiving the data. The system under consideration here is a research system and the delay in transporting, digitizing, and reformatting imagery is tolerable as long as the system is as efficient as possible. The point of the remainder of this memo will be to explore the requirements for making the data handling process efficient.

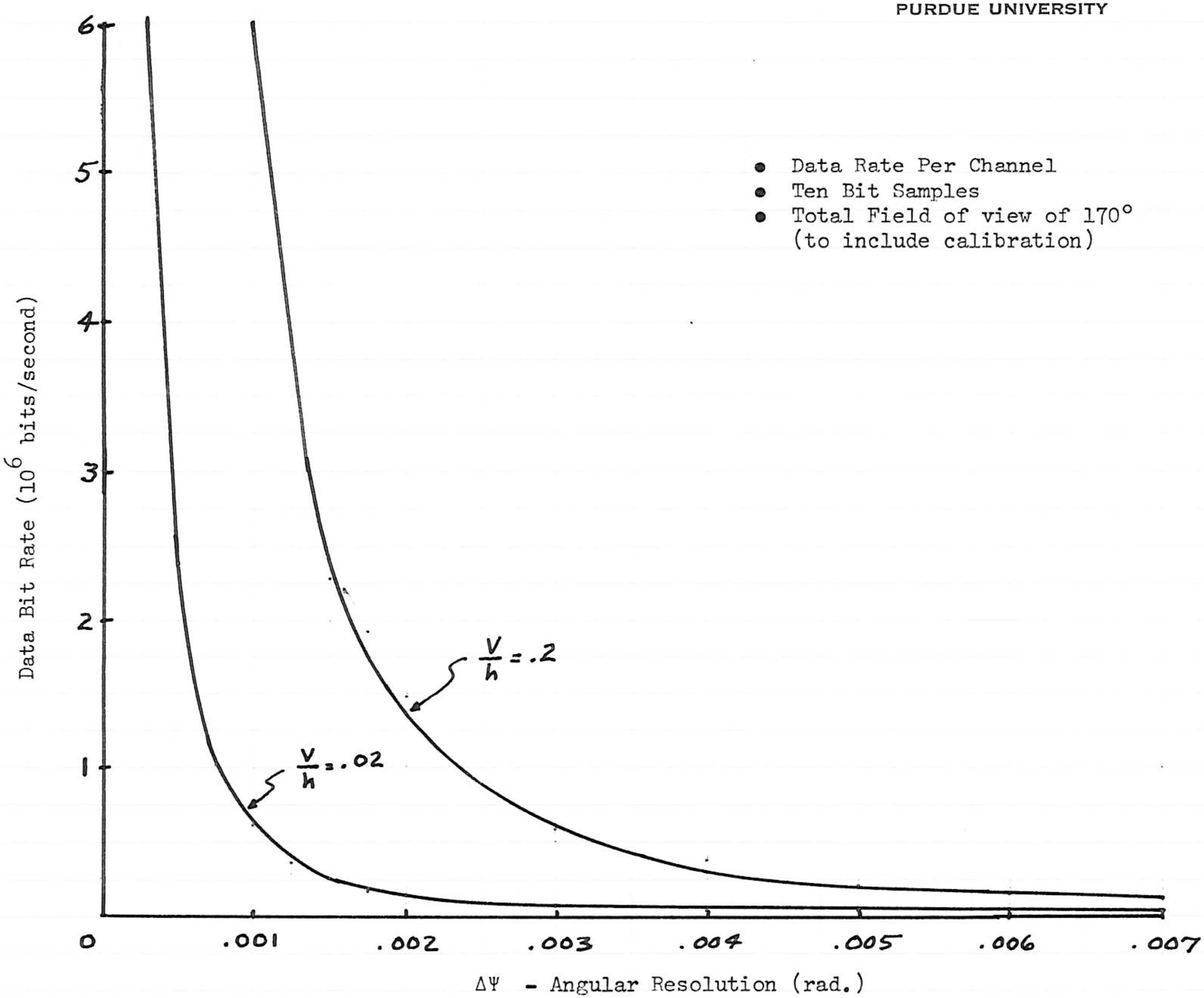

Figure 3. Data rates as function of resolution

Data Format

The present University of Michigan multiaperture scanner format gives rise to extreme data handling difficulties when combining imagery from different apertures is attempted. Also, searching for the evaluating calibration pulses requires a great amount of computer time. Calibration presently requires 7000 bytes of instruction per line and combining data from two apertures requires 14000 bytes of instruction per line. Average processing time per 1000 scanner lines for calibration and reformatting is 20 min. and for aperture combination is 90 min. Processing on this basis would be prohibitive for large amounts of data for a system requiring reasonable speed of delivery of data. For a research system, a processing load such as this could be tolerated if greatly speeded up. Clearly, the data handling load caused by having separate apertures is the most severe. Thus, the first recommendation is obviously that any scanner design be single aperture. This is presumably well understood by all concerned and is already a part of the NASA specification. These comments are included here to point out the data handling load caused by the multiaperture configuration.

Calibration Data

The second most severe data handling problem is calibration data extraction and enhancement. The University of Michigan scanner supplies two illumination source inputs and a black level reference input. Values for these quantities must be obtained and the quality evaluated and steps taken if errors are found. In the present system the analog signal generated by the scanner mirror as it passes the black level and calibration lamps is A/D converted along with the imagery portion of each scan line. The reformatting and calibration program then searches the data set for the calibration points and attempts to obtain reliable values from them. Although the positions and shapes of these pulses is reasonably predictable, variation in both attributes does exist both within a run and from flight to flight. A great deal of program complexity and time is required to get values for these pulses automatically.

An improved or advanced scanner system would clearly include some means of supplying calibration information which does not cost extra data processing time to evaluate this data.

One solution proposed during the study was to include a special sync pulse which would be placed by the scanner just in front of the calibration pulses on the output tape. The A/D system could then digitize the pulses in response to the sync pulse. This would eliminate the need for computer programs to search for the pulses. Extraction of the calibration values during A/D conversion by counting from the start sync pulse, already supplied, is another approach but considerable cost is involved as well as required operator counter adjustment. If the required calibration start pulse existed, the A/D system could always start digitizing at this point for a fixed number of samples and the calibration value extraction problem would be greatly reduced. Figure 4 shows the essence of the proposal. The A/D system would

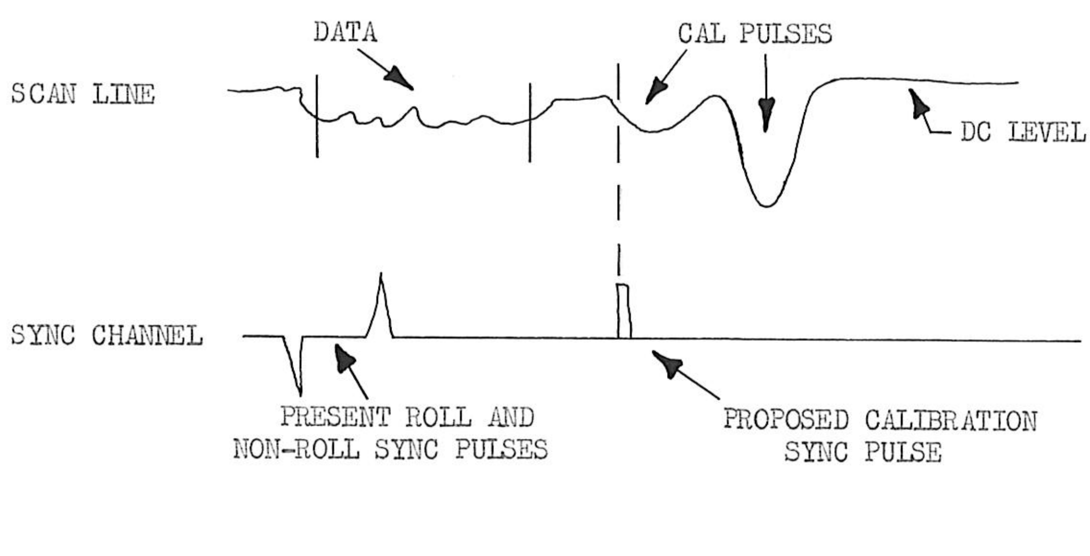

Figure 4

digitize the scanner data portion starting at the sync pulse for a given number of samples as in the present process. Instead of digitizing past the cal. and into the black reference, digitizing would be stopped before the first cal. pulse and restarted when the cal. sync pulse occurs. Digitizing would then continue into the black area.

The computer program evaluating the cal. data could then be certain that the first pulse started at the first cal. sample. Obtaining the value of the second pulse and zero level would require counting but it is assumed that the position of the second pulse would be fixed with respect to the first.

This proposal would reduce the data handling problem to a degree but the problem of getting a reliable value for the pulses still remains and will still take program time to solve. A system design effort must take this problem into account if an efficient and easily usable new scanner is to be built.

University of Michigan System Update

Some thought was given to improving the University of Michigan system as requested by guideline I. This could be done by modifying the "other end" of the present visible band scanner unit which senses energy in the .4 to 1.0 micron region. By engineering in the 8-14μ sensor with the near infrared optics already on the other end of the shaft, a "single shaft" device covering .4 to 14μ could be assembled. This would still not be a single aperture instrument, however, and the alignment would have to be very exact if coincidence in all channels was to be achieved. The calibration sync pulse could also be added. All channels could be recorded on one tape to eliminate the A/D and reformatting problems caused by separate tapes. Sensor configurations should be changed so that A/D and reformatting operations would operate on the same input format for all channels. It was suggested that these changes would be costly and the resultant unit would still be quite inadequate.

In response to II above, the present LARS A/D and reformatting system could work with the output of an updated University of Michigan configuration if the maximum number of channels was 14 and the formats of the data lines were basically the same as present. If cal. sync pulses were added, the electronics of the A/D process would have to be changed and the reformatting program would have to be modified. The electronics changes would involve additional pulse detection and gate circuitry for digitizing the cal. pulses.

Ancillary Data Recording

Reasonably firm need for the following quantities to be recorded along with the scanner line: Pitch, roll, yaw, latitude, longitude, heading, speed, and time. These items would be available in an advanced aircraft scanner system and could be recorded on a tape with some method of synchronization with the scan lines.

Data Storage

The present system uses digital magnetic tape as the primary storage media. Other forms of storage may be more desirable for large banks of scanner data. The trade offs of cost, space requirements, and efficiency and ease of use should be considered by a systems study to test the assumption that tape is the best for the imagery storage requirement. An example system with 1 mil resolution, 20 channels, and an 80° field of view is assumed. This system would produce 1400 samples per line. 8 bit digital samples are assumed. For 20 channels this would be 23,000 samples per line.

Tape - At 1600 bpi and blocking of 1 line per block, one 2400 foot tape would hold 1200 lines.

IBM 2311 Disk Pack - Storage capacity is 7.25×10^6 bytes. Average access time 75 ms, rate 156,000 bytes/sec. At 2.8×10^4 bytes per line the unit would hold 259 lines.

IBM 2314 Disk System - Capacity 240×10^6 bytes, data rate 312,000 bytes/sec. This unit would hold 8570 lines.

Data Cell - Capacity 400×10^6 bytes would hold 14,300 lines.

Drum - 4×10^6 bytes, 303,000 bytes/sec., 17.5 ms. holds 143 lines.

Bulk Core - 1.05×10^6 bytes, $306,000 purchase, 8μ sec. access. Would hold 37.5 lines.

The 2.8×10^4 sample line figure is taken only as an example for comparison. It is very doubtful that any system would take this many samples per line. Nonetheless, some interesting comparisons are observable using this figure. The capacity and access time of the large disk system and data cell appear to offer attractive storage media. In reality these systems are costly and consume large amounts of space for the storage they offer. The 2314 takes up a whole wall and rents for $5400 a month; whereas, equivalent storage on 8 tapes would cost about $200 and takes up very little space. The data cell is somewhat cumbersome in operation and was not recommended for this system by equipment manufacturers representatives. Thus, for bulk storage, the tape is clearly the most practical. Access time for tape is slow, however, and the disk systems such as the 2311 would offer high speed randon access storage for scanner lines being processed and may be a very desirable part of a digital display system.

Many other aspects of a scanner system exist which were not touched on. D.C. restoration would be a critical problem if an A.C. system was built. Measurement of absolute radiance should be possible in an advanced system and it is not clear what approach should be taken in this direction. This note describes the thoughts from only a few hours spent on the problem. Much more detailed D.H. system considerations must be made before any final scanner design is specified.

References

1. D. S. Lowe, "Line Scan Devices and Why Use Them" , Proceedings of the Fifth Symposium on Remote Sensing of Environment, Infrared Physics Lab., Willow Run Labs, Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan, September 1968, pp. 77-101.

2. NASA Statement of Work for Multispectral Scanner. (Appendix I)

APPENDIX I

STATEMENT OF WORK PRELIMINARY (APRIL 25, 1968)

MULTISPECTRAL SCANNER

I. SCOPE

This Statement of Work (SOW) defines and sets forth the overall purpose and utilization requirements for a Multispectral Scanner for use in the Earth Resources Aircraft Feasibility Test Program.

It is desired that the instrument furnished under this SOW uses proven techniques and components, therefore, rigid compliance to this general system specification is not intended. However, any deviations must be described and evaluated with regard to the system applications.

This document is subdivided as follows:

A. Applicable Documents

B. System Utilization and Objectives

C. Description of Equipment

D. Definition of Work

E. Technical Specifications (Appendix "A")

II. APPLICABLE DOCUMENTS

The specific technical specifications (Appendix "A") which are to be incorporated in the design of the Multispectral Scanner are intended to set forth minimum instrument operational/performance requirements.

Environmental requirements, as set forth in MIL-E-5400H (Class 1) related to aircraft operation at altitudes between sea level to 50,000 feet, are applicable to this instrument, as defined in Section V of this Work Statement.

MIL-STD-810A (USAF) 23 June 1964 Superseding
MIL-STD-810 (USAF) 14 June 1966
NASA Quality Publication NPC 200-2 April 1962 Edition
RA-001-007-1 January 1966 (Supplement to EPC 200-2)

III. SYSTEM UTILIZATION AND OBJECTIVES

A. This system will be used in combined multispectral experiments applied to geological, oceanographical, hydrological, and agricultural/forestry identification from aircraft. The system is required to generate the necessary information to produce a map of the radiant energy emitted and reflected in selected spectral bands from the terrain beneath the aircraft. It is desired to generate quantitative radiance maps within the extent possible after correcting by other means for attenuation and emission by the intervening atmosphere. Internal scanner calibration is required and the optical and electronic design should be optimized so that the brightness of a given object on the resulting scanner display is independent of the radiance of its environment of nearby hot and cold sources. Thus, a given density on a strip map is representative of a radiance value of an extended source.

The principal objectives associated with the use of the system are as follows:

1. To acquire and record multispectral scanning of the earth terrain in approximately twenty-five separate spectral bands in a time coincident manner. A multi-channel instrument will be required. The instantaneous field of view of the multispectral bands should be spatially coincident at all times.

2. To define means of correlating the recorded images with radiometric and spectrometric data.

3. To improve our knowledge of the intensity, contour, and distribution of geological anomalies, oceanographic and agricultural features.

4. To obtain data from this instrument that will be correlated with the data from other sensors aboard and the essential ground truth data. This data can then be analyzed to aid in increasing our knowledge of the spectral signatures of various types of terrain surface, and ocean features.

IV. DESCRIPTION OF EQUIPMENT

A. This instrument is to be a complete line scan radiometer system including the scanning instrument and a separate control and display console with provisions for manual operation in an aircraft.

B. The scanning instrument should be capable of simultaneous operation with twenty-five detector channels. Provisions are to be incorporated for providing an in-flight absolute calibration. All analog signals are to be recorded on magnetic tape, but recording equipment is an optional part of this instrument and is to be priced out separately.

Provision is to be included for inflight visual display of any one channel (strip map), selectable from all channels by switching mechanism

C. The system electronics must be capable of driving the scanning aperature in a smooth, predictable pattern at selected rates to provide adjacent scan line for V/H rates from 0.2 to 0.02 radians per second. Gates are to be provided to exclude undesirable "noise" signals during the off-duty cycle.

D. Provision shall be included to mag. tape record roll stabilization information in such a manner that it may be played back in parallel to the mag. tape recorded signal and produce a roll corrected image from the mag. tape recorded channels.

E. The control and display console shall provide for the control of all system functions and display detector outputs in both 5" A-Scope and 5" C-Scope presentations. The A-Scope will represent each line scan with X-Deflection of scan angle and Y-Deflection of instantaneous signal amplitude. The C-Scope will represent, successive framing, each line as X-Deflection, the aircraft ground track as Y-Deflection, and the instantaneous signal amplitude as spot intensity. A-Scope and C-Scope displays are to be priced out sepatately as options.

The A-Scope should be multi-channel and display the video output for any channel post amplifier. A patch panel should be provided in order that the oscilloscope can be used to monitor other signals as desired. The C-Scope should display roll corrected video of any channel. A switch should be provided for channel selection.

F. System design must be such that all system functions will operate normally from aircr[illegible] system power: 28V ±[illegible]VDC and [illegible]V±5 VA[illegible] ±20 cycle.

V. DEFINITION OF WORK

A. The contractor is to fabricate, test, and calibrate one instrument system as described, necessary to accomplish the previously set forth objectives. The proposed instrument may be a modification of an existing instrument or a new design.

B. The contractor is required to determine and provide any necessary ground support equipment (GSE) required for "field" operation of this instrument.

C. The contractor shall perform such tests on this instrument to verify the performance requirements and to determine signal degradation caused by the following environmental conditions (as defined in MIL-E-5400H). Paragraph 3.2.21 - "Service conditions (environmental)."

1. Temperature - 3.2.21.1, 3.2.21.1.1, and 3.2.21.1.2
2. Vibration - 3.2.21.5, 3.2.21.5.1, and 3.2.21.5.2
3. Shock - 3.2.21.6, 3.2.21.6.1, and 3.2.21.6.2
4. Altitude - 3.2.21.2
5. Temperature-altitude combination - 3.2.21.3

Equipment performance shall be within specifications when subjected to the environmental conditions above when performed in accordance with the methods of MIL-STD-810A for Class 1 equipment.

APPENDIX "A"

TECHNICAL SPECIFICATION

FOR

MULTISPECTRAL SCANNER

TECHNICAL SPECIFICATION

FOR

MULTISPECTRAL SCANNER

1.0 GENERAL

The Airborne Multispectral Scanner called for in this specification shall exhibit the highest possible degree of reliability.

1.1.1 Mechanical and Optical Requirements

1.1.1.1 Collecting Aperature: 12-inch maximum, 6-inch minimum.

1.1.1.2 Resolution: 1 milliradians (approximately)

1.1.1.3 V/h: 0.2 to 0.02 Rad/Sec

1.1.1.4 Angular Coverage: a80 degrees (±40)

1.1.1.5 Wavelength regions of operation, 25 channels within 0.3 to 14 microns.

1.1.1.6 Maximum Scanner Size: 2 ft. wide x 3 ft. high x 4 ft. long (overall dimensions).

1.1.1.7 Detectors are to be selected to optimise the 25-channel band. One spare of each detector will be provided.

1.1.1.8 Detector Mounting: Provisions to facilitate detector replacement, alignment, focusing, and replacement of optical components.

1.1.1.9 Cooling: Provide for (10) hours operation of detectors. Reliability - 400 hours between maintenance of any sort.

1.1.1.10 Means shall be provided for absolute inflight calibration of the scanner preferably in a continuous or quasi-continuous basis. At least two standardized and controlled infrared sources and a standardized and controlled U/V-visible source together with a zero reflectance (black) reference level are required with means for introducing these into the scanner beams at appropriate times.

1.1.1.11 Optical resolution of collecting optics should be better than 0.5 milliradian blur circle diameter.

1.1.1.12 Proposal should demonstrate that the overall efficiency of the system has been maximized while remaining compatible with system specifications.

1.1.1.13 Provision shall be incorporated within the system to provide timing and aircraft location information (ASQ-90 format) directly on the mag. tape.

1.1.2 Electrical Requirements

1.1.2.1 General

1.1.2.1.1 Output ±1.5 V maximum

1.1.2.1.2 The frequency response of this system must be such that a square wave signal, whose frequency corresponds to the scanning head scan rate, will have a droop of less that 1 percent. In addition, the frequency response must be such that a pulse whose length corresponds to scanning a point source at maximum V/H rate, will reach at least 90 percent of its true value.

1.1.2.1.3 No DC level shift from gate on (video) to gate off (Electronic calibration).

1.1.2.1.4 Thermal and other drift to be less than 100 MV at the output.

1.1.2.1.5 Amplifier chain must be such that the system is detector noise limited.

1.1.2.2 Preamp

1.1.2.2.1 Each preamp must provide the necessary bias and/or high voltages required for proper operation of its associated detector.

1.1.2.2.2 Be capable of handling 2 MV P-P signals for photoconductive detectors and 10 MV P-P signals for photoemissive detectors on top of common mode signal which may be as large as 5V.

1.1.2.2.3 Gain 60 DB ±6 DB (for photoconductive) and 1, 10, 100 (switched for photoemissive detectors).

1.1.2.2.4 Wide Band noise figure 5 DB or less (with matched loads) in all cases.

1.1.2.2.5 Low Output Impedance: Suitable for driving gated output signals through 50 feet of cable with suitable pressure fittings.

1.1.2.3 Gate

1.1.2.3.1 Shall introduce no DC level shift when gating video on and off.

1.1.2.3.2 During the time that video is gated off, gate the electronics calibrate signal on.

1.1.2.4 Post Amplifiers

1.1.2.4.1 Gain adjustable in steps 1, 2, 5, 10, etc.

1.1.2.5 Sweep Circuitry

1.1.2.5.1 Provide roll correction to be accurate within 0.5 milli-radian over the range 8 degrees left to 8 degrees right roll up to 8°/sec aircraft roll/rate.

1.1.2.5.2 Provide a low impedance 2.8 volt peak-to-peak square pulse output such that the positive pulse voltage may be used to gate the video on.

1.1.2.5.3 Provide two additional low impedance roll corrected pulse outputs suitable for triggering monitor oscilloscopes (A-Scope and C-Scope).

1.1.2.6 Scan Speed Control

1.1.2.6.1 Provide automatic variation in scan speed to provide continuous scan lines for manually selected V/h ratios in the range of 0.2 to 0.02.

1.1.2.6.2 Hold selected scan speed constant within ±0.05% over a 500 millisecond sampling period.