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LARS/U. of Michigan Aircraft Scanner Data System Parameter Identification Study

by
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A list of significant LARS/U.M. aircraft scanner data system parameters has been assembled for the purpose of planning a detailed analysis of system performance. The goal of this study was to specify all parameters which significantly effect system performance.

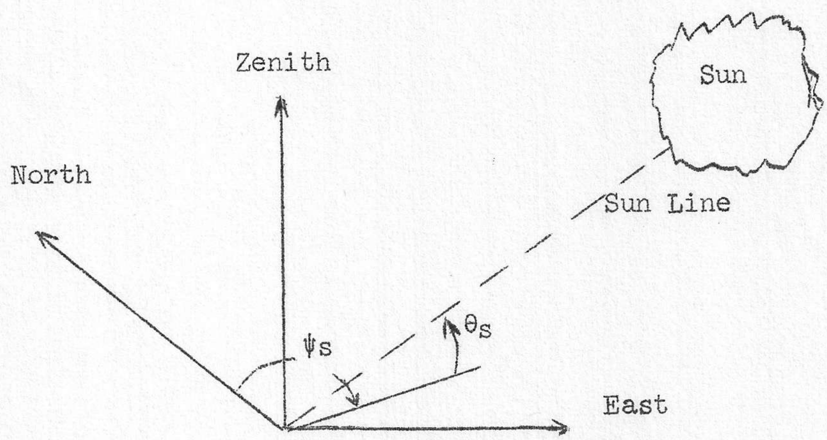
The LARS aircraft scanner data system can be represented as four separate subsystems or blocks with inputs and outputs as shown in Figure 1 with some of the most significant parameters listed. The physical environment block is essentially independent or uncontrollable and includes the source of energy - the sun; as well as the key parameters: Target, ρ - reflectance, ϵ - emissivity, and T - temperature. The scanner block represents the physical scanner and aircraft and is the key element in the measurement system. The A/D block represents the data transmission, recording, reproducing and analog to digital conversion processes and all factors that influence it. The block begins at the sensor output terminals and ends at the digital tape on which the imagery is stored as it comes from the A/D system. The reformatting block represents all computer operations on the data involved in producing the final aircraft data storage tape.

I. Physical Environment

The physical environment is technically not part of the scanner data system; however, the physical parameters are intimately involved in all parts of the system. Partial knowledge of the characteristics and values of the physical parameters can aid in improving system performance. The significant parameters are:

1. Sun Angles θs and ψs. The sun angles can be expressed in terms of azimuth with respect to north, ψs, and elevation, θs. These angles are a function of time of day, latitude, longitude, time of year, and year.

azimuth: horizontal direction expressed as the angular distance between the direc. of a fixed pt. and the direc. of the object.



Thus the sun angle is explicitly expressible as a function of ephemeral quantities:

$$\theta s = f_\theta(X, \phi, GMT, DAY, YEAR)$$

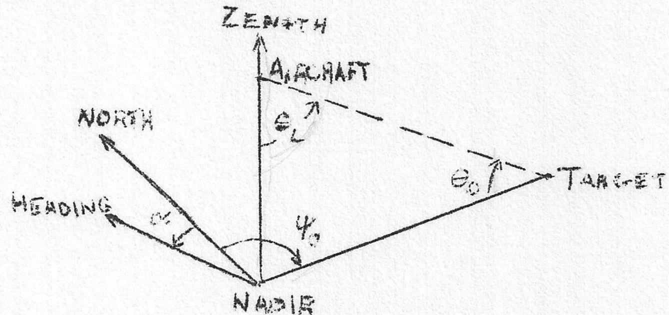
$$\psi s = f_\psi(X, \phi, GMT, DAY, YEAR)$$

Where: X = Latitude

ϕ = Longitude

GMT = Greenwich mean time

The observation angle of the scanner can be determined from the heading of the scanner and the look angle:



θ_o observation angle = $90 - \theta_L$ Look angle

and ψ_o observation azimuth = α(heading) + 90°

The relationship between the sun line of sight and observation line of sight can then easily be determined from θ_o, ψ_o, θ_s, ψ_s.

2. Wavelength λ: Fundamental variable describing the electromagnetic energy being observed.

3. Solar irradiance - H_λ(Watts $cm^2 . \mu$) is the total electromagnetic energy reaching the vicinity of the earth from the sun. The sun is essentially a blackbody at a temperature of 6000° Kelvin and radiates energy over an extremely broad band. The aircraft scanner system is sensitive to energy from .3 microns to 14 microns which is reflected and reradiated from the target. The intensity of the sun evergy over this span of wavelengths must be known for proper calibration of the sensors. Figure 2 contains a graph of the irradiance from .2 to 3.2 microns.

4. Atmospheric Transmission τa: The transmission of electromagnetic energy varies with wavelength and the state of the atmosphere.

Scattering and absorption effects are included in this parameter at a particular wavelength. Figure 3 illustrates the transmission windows from 4 to 26 microns.

5. Reflectance ρ: This is a key parameter in the physical process observed by the scanner. It is a function of the material observed, its surface characteristics and environmental factors.

6. 7., Emissivity ϵ, Temperature T: ϵ is the parameter which determines the amount of energy radiated by a material as a function of its temperature T. The emissivity is a function of wavelength.

II. Scanner System Parameters

The optical mechanical line scanner utilizes a rotating scanning mirror and spectrum splitting optics to multispectrally sense the electromagnetic energy emanating from a line in the target area perpendicular to the axis of the scanning mirror[1,2]. The energy received by the optics is directed to detector material which transforms it into an electrical output signal. The usual method of specifying the sensitivity of a detector is the noise equivalent change in energy detectable. This figure is based on the assumption that a signal change equal to the noise can theoretically be detected. The following expressions are taken from reference 1.

1. The noise equivalent reflectance change detectable is given by the following expression.

$$NE\Delta\rho = \frac{4F_d \Delta f^{\frac{1}{2}}}{\tau_\alpha H_\lambda^{\Delta\lambda} \cos\theta_s D\, D_\lambda^* \, e\, \beta}$$

Most of the significant scanner parameters are in this expression. The parameter which determines most of the design requirements after a suitable $NE\Delta\rho$ is specified is β the angular resolution.

2. Angular Resolution β (radians): The angular size of the resolution element of the scanner. The nominal diameter of the target area covered by the scanner beam is βH at nadir. (H is the altitude).

3. F_d is the F number of the optics.

4. Δf is the noise bandwidth:

$$\Delta f = \frac{\pi (V/H) \psi}{2\, q\, e_1\, \beta^2}$$

This bandwidth is that required to sense a 98% change in the dynamic range of the input at the scanning rate dictated by (V/H). It is called the noise bandwidth since source and sensor noise will be admitted to the system over a bandwidth of Δf.

5. (V/H) is the velocity altitude ratio of the aircraft carrying the sensor. This parameter determines the data rate produced by the scanner.

6. ψ is the angular field of view of the scanner. The approximate width of the scan beneath the craft is $2H \sin \left[\frac{\psi}{2}\right]$.

7. q is the number of detectors operating in concert to reduce the data rate from any one sensor.

8. e_1 is the overall scanning efficiency. This quantity indicates the amount of redundant data produced by the scanner.

9. e is the optical efficiency of the scanner. This parameter represents the losses in mirrors, lenses and other optical paths.

10. $\Delta\lambda$ is the width of the band over which energy is being sensed for a particular detector.

11. θs is the sun angle assuming the scanner look angle is 0°.

12. D is the diameter of the scanner collecting mirror.

13. D^{*}_{λ} is the detector material figure of merit and has units of cm. $cps^{\frac{1}{2}}$/watts.

This expression defines the scanner sensitivity for reflectance measurements. Determination of the values of the parameters is the sensor design problem. Given a β and required $NE\Delta\rho$ all the other parameters must be determined by engineering design procedures.

14. Measurement of thermal infrared radiations requires different detector materials than for reflective measurements and the noise equivalent temperature change detectable is given by:

$$NE\Delta T = \frac{\lambda T^2}{14,388} \; \frac{4F_d \; \Delta f^{\frac{1}{2}}}{\tau a N_\lambda \Delta\lambda \pi D D^{*}_{\lambda} e \beta} \quad \text{in } ^{\circ} \text{Kelvin}$$

15. T is the temperature in $^{\circ}K$ of the target element being viewed by the scanner.

A typical set of parameter values for current aircraft scanners is presented as an example to give physical feel to the parameters.

β = 3 Milliradians

D = 6 inches

e_1 = 25%

e = 10%	$.3\mu \leq \lambda \leq .4\mu$
25%	$.4\mu \leq \lambda \leq 6\mu$
40%	$\lambda \geq 6\mu$

$F_d = 2$

$D^*_\lambda = 3.4 \times 10^{11}$ cm cps$^{\frac{1}{2}}$/watts (Silicon Detector)

$\psi = 80^\circ$

$q = 1$

$V/H = .2 \text{ sec}^{-1}$

$\theta_s = 45^\circ$

$H_\lambda = 20$ watts M^2/millimicron (Sunny Day)

$\tau a = .5$	$.4\mu \leq \lambda \leq .7\mu$	
$.7$	$.7\mu \leq \lambda \leq 5\mu$	(In the windows)
8	$\lambda \leq 8\mu$	(In the windows)

The noise equivalent $\Delta\rho$ and ΔT values are as follows:

	Band	No. of Chans.	% $\Delta\rho$ or ΔT Change Detectable
Silicon	$.3 - 1.1\mu$	10	.044
Indium Arsenide	$1.18-1.75\mu$	2	.066
	$2.1-2.4\mu$	1	.098
Indium Antimide	$3.5-4.0\mu$	1	.58
	$4.5-4.7\mu$	1	.9
Mercury Doped Germanium	$8.3-13\mu$	1	.11 - .22

These parameters determine the data rates and accuracies which the data handling system must handle. Two other critical parameter classes must also be included in any system parameter study: Stabilization, and calibration.

The image data stability problem is due to variations in six spatial dimensions of the scanner platform. The effect of these variations must be removed if spatial integrity is to be achieved in the imagery.

16. Altitude H; The distance from the craft to the target must be accurately known. Variations in H are due to terrain height variations or aircraft altitude above sea level variations.

17. Lateral position variations can be caused by crosswinds or craft navigation errors.

18. Along-track variation in craft velocity V can cause scale variations in the imagery in the along track dimension. Velocity variations can be due to many causes such as engine speed variations, headwinds, craft drag changes, etc.

The angular orientation quantities

19. Pitch - Aircraft rotation about its lateral axis

20. Roll - Aircraft rotation about its longitudional axis

21. Yaw - Aircraft rotation about the vertical axis

can have a disastrous effect on the performance if they are not well controlled. The University of Michigan scanner is strapped down to the aircraft frame and is electronically stabilized only in roll. Thus yaw and pitch angle effects will be seen in the scanner imagery. Small variations in these three quantities do not seriously effect multispectral pattern recognition system results. However, the geometric properties of the imagery can be badly distorted making registration and human interpretation extremely difficult. Thus, the value of these parameters is important and should be considered in a system parameter study.

The characteristics of the calibration sources are critical to the determination of the absolute scene reflectance and radiance. The key relationship in determination of the absolute radiance is the calibration lamp output as a function of lamp current for each wavelength band.[3]

For thermal calibration the emissivity and temperature of heat plates as a function of input current must be accurately known. Clearly the precise current through each calibration source must also be known.

22. Lamp radiance as a function of wavelength and current.

$R = f(\lambda, I)$ Units are (watts per square centimeter - micron-steradian)

23. Lamp source current I - Lamp and heat plate currents.

The scanner response as a function of angle is known to vary and this problem must also be quantified and compensated for. Only a general functional parameter will be specified here.

24. $\Delta R(\theta, \lambda)$ Angular response deviation.

ΔR is the deviation factor as a function of look angle θ referenced to nadir, and wavelength λ.

Ephemeral data such as:

25. Latitude

26. Longitude

27. Time

28. Day of Year

29. Year

30. Temperature profile of sensing environment

are important parameters which are necessary for cataloging stored data and for performing certain stabilization corrections.

Many other scanner parameters exist, and it is the purpose of this list to point out only the most significant ones. Further study is required into each facet of scanner design if meaningful improvements are to be made in the scanner.

III. Analog Data Recording and Conversion

The analog portion of the system includes amplifiers, tape recorders and the A/D system and all signal influences associated with them.

A. Detector to Analog Recorder

1. BW_A: Amplifier Bandwidth

2. N_A: Amplifier Noise. Hum, thermal noise, drift and AGC effects are included. Also expressible as S/N_A - Preamplifier signal to noise ratio.

3. G_A Amplifier gain as it effects signal accuracy.

B. Analog Recorder Effects (Aircraft, duplication, and A/D system recorders)

4. BW_R: Bandwidth and frequency response of all record reproduce Electronics and recorder.

5. N_R: Noise. Wow, Flutter, tape, noise are included.

6. G_R: Record and reproduce gains that effect accuracy.

C. A/D Effects

7. $BW_{A/D}$: Bandwidth of amplifiers in A/D system.

8. $N_{A/D}$: Amplifier noise in A/D analog portions.

9. N_Q: Quantization in A/D: Number of bins used to convert signal to digital form.

10. Sample and hold errors. This determines the A/D conversion accuracy along with N_Q.

11. Crosstalk: Interference between channels in A/D converter and associated elements.

12. A/D Linearity: Refers to the linearity in output value with respect to input value.

13. f_s: Sample Rate. The signal sample rate determines the amount of information extracted from the input data.

The recording and conversion segment of the system starts at the detector terminals and ends at the bulk digital data tape produced by the A/D system. Data volume considerations enter here since recording and transmission systems must be designed to handle the desired rates. The data rate in bits per second is given by:

14. $$BW = \frac{\psi(V/H)NB}{\beta^2} \qquad \text{Bits/second/channel}$$

NB = Number of bits per sample

and the total rate is

15. $$BW_T = BW \cdot NC \qquad \text{Bits/second}$$

NC = Number of Channels

A/D processing time and storage media volume requirements are determined from these parameters.

IV. Digital Data Handling Parameters

The scanner imagery is reformatted, calibrated, and overlayed in the preprocessing operations which create the final data storage tape.

A. Calibration: The chief factor and problem in the preprocessing phase is the evaluation of the calibration information available from the scanner which is included in the analog output signal. Four quantities exist in the present system:

1. Black or reference level
2. Calibration Lamp or heat plate 1.
3. Calibration Lamp or heat plate 2.
4. Sun sensor illumination signal.

All four may not be present in one run. The system problem is to find these pulses and accurately determine their value. Determination of and utilization of the physical characteristics of the calibration sources is also a digital pre-processing system problem.

B. Overlay: Imagery from different channels and different times must be stored in spatial congruence if multispectral analysis or multi-image enhancement is to be performed. Where image is not in registration correlation and shifting must be carried out to align the data. (See references 4 and 5.) Parameters influencing overlay are:

5. Translational Misregistration in 2 dimensions
6. Rotational Misregistration
7. Scale Differences in 2 dimensions
8. Type of surface structure in the imagery
9. Availability of reference grids and estimates of misregistration.

The final element which must be considered is the data storage and retrieval system which makes the data available to the user. Two functions are necessary to retrieve the data: Volume retrieval and point retrieval. Data volume retrieval for a tape storage system is facilitated by use of a tape number and file number. Added flexibility is achieved through use of a data set or run number which uniquely identifies the volume.

10. Run Number: Unique data set identifier
11. Tape Number: Volume identifier for tape where the run is stored.
12. File Number: File on the tape where the run is stored.

A run file can be maintained which facilitates computer operator retrieval of the data asked for by the user.

Data point retrieval requires a three dimensional coordinate system which facilitates computer acquisition of the desired point from tape after the file has been found.

13. Line Number - Along track coordinate of the data point.
14. Column Number - Across track coordinate of data point.
15. Channel Number - Tape channel where data from a particular wavelength band is stored.

Other parameters in the retrieval system include the mode of data calibration used on the data. The parameters given here are the basic ones only. The current data calibration facility is described in reference 6.

The 68 parameters listed in this note form a basis for an integrated study of a digital aircraft scanner data system. It is intended as a reference for those beginning a study of such a system to improve its performance.

REFERENCES

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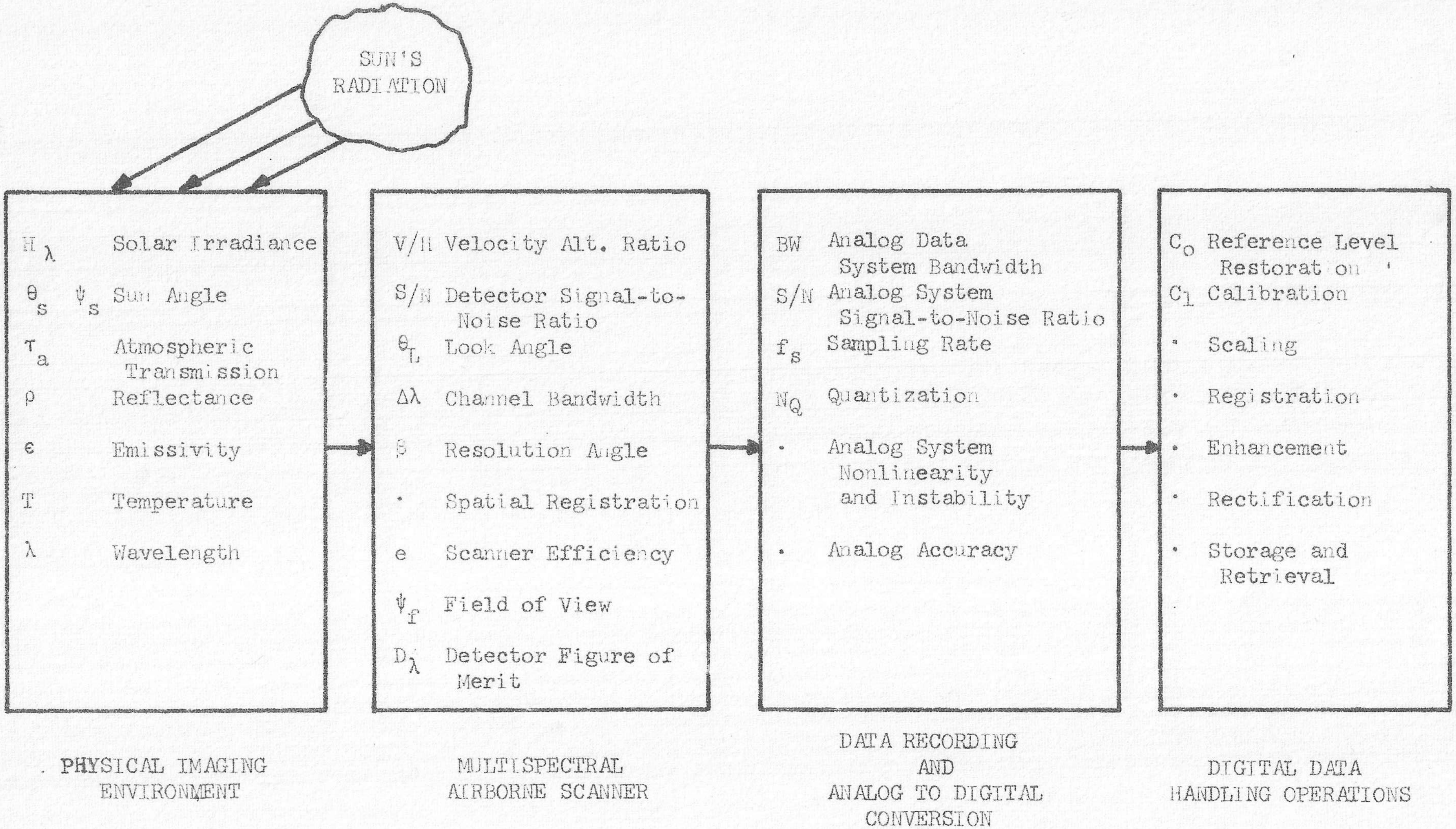

FIGURE 1 AIRBORNE MULTISPECTRAL SCANNER DATA SYSTEM ELEMENTS