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3.2 REPORT OF SUBPANEL ON IMAGE SHARPNESS

The image sharpness subpanel met for a four-hour period on November 18 and again for four hours on November 19 to define research needs in this subject area for earth resource observation systems. The panel consisted of:

Bob Barker	St. Regis Paper Co.
Bill Shelley	St. Regis Paper Co.
Bill Alford	NASA/Goddard
Orback Zvi	Honeywell E.O.O.
Marvin Maxwell	NASA/GSFC, Code 920
Arch Park	G.E. Lanham, Md.
Jack Engel	Santa Barbara Resch. Ctr.
Demetrios Poros	G.E. Lanham, Md.
Joseph Kundholm	NASA/GSFC
Peter Hyde	Un. of Md. Cmptr.Sci.Ctr.

The format for the subpanel given as a starting point was followed in the initial discussions, but as time was short, it was decided to focus on the task descriptions and the expected costs. The required items are included here to the extent they were discussed and further information is to be added later.

3.2.1 Definitions

Initial discussion considered the definitions of the various functions and parameters defining the sensor scene viewing process. Conflict with existing definitions occurred throughout and no consensus could be reached in the short time without adequate references. The panel adopted the conventions that are described and used in NASA SP-335, Advanced Scanners and Imaging Systems For Earth Observations. Special reference is made to the section entitled "Resolution Improvement Considerations" on pages 89 through 103 and on the section entitled "Definitions Pertaining to Resolution and Sample Data" on pages 105 through 109.

PSF - Point Spread Function: blur due to optical elements in system

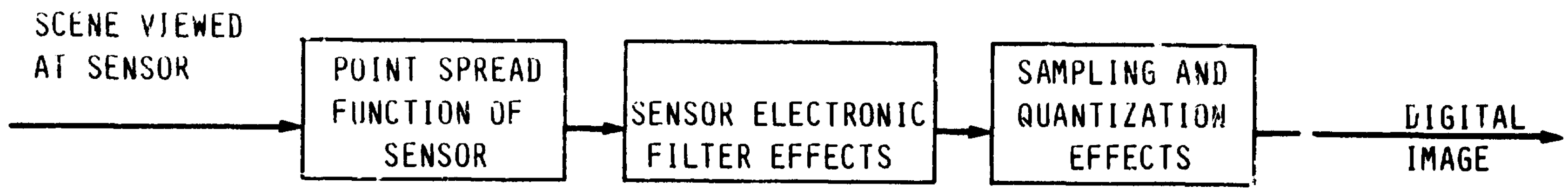
IFOV - Instantaneous Field of View: aperture width in scanner sensor system

EIFOV - Effective Instantaneous Field of View: composite blur function after filter effects, PSF, and IFOV have been combined.

These are really working definitions to allow panel members to separate the blur components of the sensor. They are not to be widely applied. Figure 1 depicts these steps. It was natural to have the thinking focus on multispectral scanners and not on all the sensors which are of interest. These other sensors include: Imaging Synthetic Aperture Radar (SAR), Separate Thermal IR Images (HCMM), Multispectral Linear Array (MLA). The MLA contains unique characteristics which set it apart from the scanning optics of TM and MSS, so it is called out separately.

3.2.2 State of Knowledge

The parameters defining the state of the art in sharpness were discussed but not quantified. It was generally assumed that TM was the state of the art in



OTHER FACTORS

POINT SPREAD FUNCTION OF ATMOSPHERE
ATMOSPHERIC SCATTERING

FIGURE 1 FACTORS RELATED TO SHARPNESS

multispectral scanners and the digitally processed SAR was state of the art in radar. Order of magnitude numbers are included in some cases.

Sensor:	Atmospheric Blur/Scatter Function	
	Optical PSF	
	Scanner Aperture	30 m
	Filter Characteristics	
	Sample Rate	30 m
	Quantization	8 bits
Ground Processing:		
	Effects of Resampling on Sharpness	cubic convolution
	Sharpening Filters	Much work done but not used
	Sharpness Effects on Classification	a few studies
	Atmospheric Connection	A few users doing

3.2.3 Requirements

Discussion initially focused on whether sharpness was to be considered from the standpoint only of registration or of impacts on classification as well as registration. It was decided that unusual sampling rates would be needed in the future to enable improved sharpening of images through deconvolution. Present sampling rates are too low to allow much improvement. Severe noise effects arise even when moderate improvement is attempted. Requirements were cited for sharpening in the context of forestry applications: a) resolution of mixed (edge) pixel problem (improved classification precision, reliable change detection results, more precise areal estimates); b) improved rectification (improved definition of manually located GCP locations, verification of cartographics).

3.2.4 Recommended Research Tasks

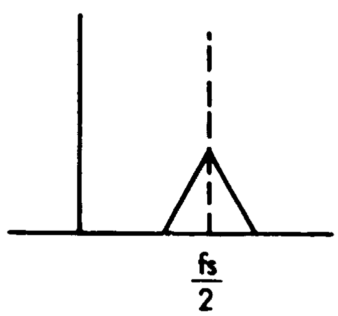
Several key research tasks were proposed and are listed here:

I. Study of Relationships of IOVF or Performance of Matching: Unenhanced, raw data is being used for template matching in major image geocorrection systems (e.g., MDP). Sharpening processes appear to produce more visual detail. This apparent sharpness could reduce position errors in template matching. Various sharpening techniques should be applied to images before matching. Since nonlinear processes are used for matching, usual linear analysis cannot be used. Performance should be measured by experiments with real data.

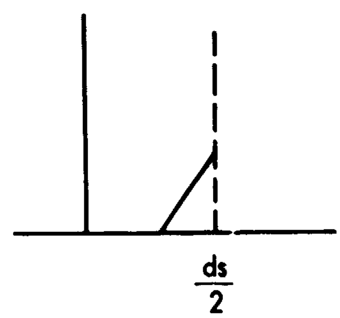
II. Conduct a study to determine the "optimum" shape for the Effective Instantaneous Field of View (EIFOV) and the sampling lattice to allow the generation of an Output EIFOV (OEIFOV) in the sharpening or resampling operation which is "optimized" for various applications such as photomap generator, multitemporal multispectral classification, etc. In the study the variations in EIFOV shape, size, and sample spacing in x and y will be construed to keep the system cost approximately constant by keeping the number of detectors or the data rate constant.

III. Optical Prefilterting: We proposed to research the advantage of an optical filter, to filter the image data before it reaches the "detector array." It seems that for a system like MLA, where the image data is sampled by a distinct detector array, an antialiasing optical low-pass filter can be very helpful. In fact, an antialiasing filter for such a system can only be an optical filter. It also seems that such an optical low-pass filter may be more easily achieved than time-domain electronic low-pass filters. Therefore we recommend that a research be established to evaluate the needs and the practical feasibility of an optical low-pass filter for an image-sampling-type camera in order to avoid aliasing.

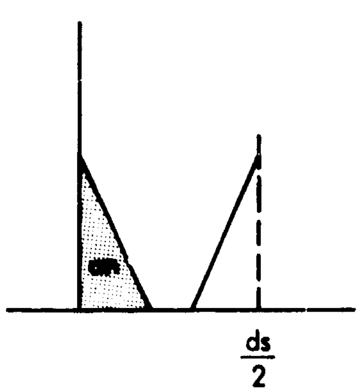
The sampling theory states that in a sampling-type system, a prefilter is required to avoid aliasing.



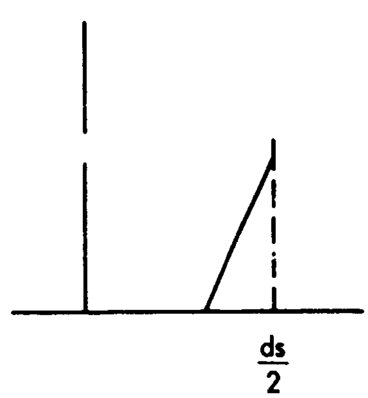
1.a. Original signal



1.b. The signal after ideal low-pass filter of fs/2



2.a. Original signal after sampling and reconstruction (an = aliasing noise)



2.b. Filtered signal after sampling and reconstruction

As it is described by Figures 1a, 1b, 2a, and 2b, the sampling theory states that if the sampling rate is fs, the output has no frequency content above fs/2, or the input will appear as aliasing noise at the output. Sampling systems in the time domain are very common today. In practice, a project time-type low-pass filter cannot be achieved, and so a lot of systems use oversampling to avoid aliasing noise. The new generation of ground observation imaging devices like MLA use a detector array approach. Such a system is image sampling and obeys the sampling theory. As such, any spatial frequencies greater than the half-sampling frequency will appear at the detector output as an alaising noise. At that point the removing of the noise from the real image is hardly possible. It then seems that the image data should be filtered before it is sampled by the detector array. Such a filter could only be optical. It also seems that a spatial optical low-pass filter can better achieve the ideal performance since the whole data exists instantaneously as opposed to time type of filtering. When the signal from $t = -\infty$ to $t = +\infty$ cannot be available to the filter, the optical filter then should be part of the optical subsystem used to bring the image data to the detector array. A research should be established to evaluate what kind of benefit would come out of an optical filter in front of the detector array imaging devices. The performance of a low-pass optical filter should be studied. The problem of different optical bands should also be considered. The final result of such research should be the requirements for a low-pass optical filter for a specific detector array, and whether or not such filter is cost effective at all.

IV. Utilization of DOD Capabilities by NASA

An effort should be made to establish the state of the art on the capability of the Department of Defense and the intelligence community to produce image processors for sharpening (also resampling and feature extraction), to establish if their techniques could be useful to civilian applications. Efforts could then be made to have this information declassifed and made available through publication in the open literature.

V. Investigation of Effects of Diffraction

Appropriate compensation (sharpening) techniques need to be developed for use on data in which the dominant cause of the image blur is defraction. Advanced Thermal IR MLA sensors and passive microwave sensors will be "Defractor Limited." Study should be conducted to establish the technique that would be used and the performance improvement to be expected as a function of the scene characteristics.

VI. SAR Image Sharpening

Research activity in support of synthetic aperture radar (SAR) must be identified, but there was no member of the panel with real experience in SAR processes or interpretation. These tasks should be addressed later with appropriate people providing the needed inputs.