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PROCESSING SYSTEM TECHNIQUES FOR THE 80's

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I. ABSTRACT

Increased spatial resolution of oncoming systems such as Thematic Mapper and the French SPOT, plus experience gained in the LANDSAT MSS lead to a requirement to understand the error sources in the scene-to-data tape portion of a remote sensing system. An evaluation of this portion of the system and its effects on processing remote sensing data derived therefrom is presented. Discussion is limited to passive sensors in the reflective portion of the spectrum.

II. INTRODUCTION

A recent NASA study (1980) to define fundamental research issues in remote sensing contained a portion entitled Mathematical Pattern Recognition and Image Analysis. A recurring theme in a draft report on the issues associated with preprocessing was a need to better model the scene, sensor, and sensor platform both geometrically and radiometrically. There was a sense that, while in the 70's machine data analysis and information extraction techniques could make a giant step from gross ground truth scene descriptions directly to LANDSAT data tape pattern recognition processes with some success, things had progressed to a point demanding more finesse. In particular, the need for multitemporal overlays in LACIE, awareness of mixed pixel effects and their aggravation in misregistration, the failure of signature extension, atmospheric effects problems, and a host of issues attendant to resampling, have all fostered an increased interest in the parts of the system, both natural and designed, that exist from the scene itself to the data tapes available to the user. The refined instantaneous fields of view of Thematic Mapper and the French SPOT system, the ability for sizeable offset from nadir in the SPOT system, and the thrust toward high resolution multispectral linear array scanners in this country will increase the need for system understanding including the preprocessing techniques employed by the initial on-board and preprocessor, be it NASA/GSFC, the Centre de Rectification des Images Spatiales, or whomever.

The preprocessing techniques for (1) registration through gross correlation or other similarity measures, decomposition into subimages, and further error minimization polynomial modeling against similarity thresholds (2) rectification to ground control points through polynomial mappings (3) resampling with spline interpolation (4) and radiometric smoothing on striping or drop-out high-frequency artifacts or atmospheric and sun angle normalization for low frequency effects began development in the late 60's and reached states of acceptable fruition in the mid to late 70's. Except for the mixed pixel effects, the large MSS instantaneous field of view and a more than adequate sampling rate have been forgiving features of this era. This paper will seek to explore some of the facets of the scene-to-data tape part of the system that will impact processing in the 80's.

III. BEFORE THE SENSOR IS THERE

The photon radiance field that is present at a point in space, $\vec{r}$, due to the Sun and reflective source at $\vec{r}'$ described by a bidirectional reflectance distribution function $\rho'_\lambda(\vec{r}',\hat{k},\hat{k}_\odot)$ is, <u>in the absence of an atmosphere</u>

$$L_\lambda(\vec{r}',\hat{k}) = \rho'_\lambda(\vec{r}',\hat{k},\hat{k}_\odot)H_{\lambda\odot}\,|\hat{n}\cdot\hat{k}|$$

where $H_{\lambda\odot}$ = solar spectral radiance at one A.U. from the Sun, $W/m^2\text{-}\mu m$)

$\hat{k}$ = unit propagation vector in the direction $\vec{r} - \vec{r}'$

$\hat{k}_\odot$ = unit propagation vector emanating from the Sun

$\hat{n}$ = unit surface normal at the reflective surface

The power received on an aperture of area A at $\vec{r}$ normal to the nadir direction in a wavelength increment λ to $\lambda + d\lambda$ is

$$dP = L_\lambda(\vec{r}', \hat{k}) A \cos\theta_n d\Omega d\lambda$$

where $d\Omega$ is the solid angle element of the patch of ρ'_λ at $\vec{r}'$ seen from $\vec{r}$. Figure 1 describes the geometry.

The presence of a scattering, absorbing, and refracting atmosphere does much to destroy the simplicity of the relations above. The radiative transfer problem must be solved, which is complex even for the reasonable model of a homogenous planar atmosphere. (Monte Carlo calculations for a spherically symmetric Earth atmosphere show that the results differ insignificantly for a plane-parallel approximation except at twilight sun angles, even to polarization variables.(1)) Downward radiance at the reflective source includes direct solar contributions and diffuse sky radiance which includes photons that have never interacted with scene reflectances and photons that have interacted once or more with either the reflective source at $\vec{r}'$ or adjacent reflective sources near $\vec{r}'$. Rigorous formal solution of the one-dimensional planar atmosphere requires uniform surface reflectance characterization independent of $\vec{r}'$, which is not often the case in interesting scenes. Thus, true modeling of atmospheric effects over Earth scenes requires a three-dimensional solution of the radiative transfer problem.

For an optical thickness τ, and cosine of the solar zenith angle of μ_o, the radiance of a small area of surface at the surface location in the direction $\hat{k}$ is

$$L_\lambda(\vec{r}', \hat{k}) = \rho'_\lambda(\vec{r}', \hat{k}, \hat{k}_\odot) H_{\lambda\odot} |\hat{n} \cdot \hat{k}_\odot| \exp(-\tau/\mu_o) + \int_H \rho'_\lambda(\vec{r}', \hat{k}, \hat{k}_i) L_\lambda(\vec{r}', \hat{k}_i) |\hat{n} \cdot \hat{k}_i| d\Omega_i$$

where $\int_H$ stands for a hemispherical solid angle integral over the incoming directions $\hat{k}_i$. Incoming incremental irradiance, $L_\lambda(\vec{r}', \hat{k}_i)|\hat{n} \cdot \hat{k}_i| d\Omega_i$, of the scene will contain photons that have interacted with the surrounding scene one or more times and photons that have not yet interacted with the scene. Some recent efforts

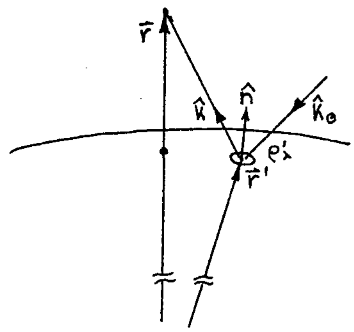

Fig. 1 Remote Sensing Scene Geometry

(2,3,4) to model atmospheric effects over non-homogenous Lambertian or non-Lambertian surfaces yield results which can be paraphrased in radiance terms. The radiance well above an atmosphere whose properties vary only with altitude is of the form

$$L(\vec{r}, \hat{k}) = L_o(\vec{r}, \hat{k}) + \frac{H}{1 - ab}(A\rho'_\lambda + B\bar{\rho}'_\lambda + Ca/\pi)$$

where
$$H = H_{\lambda\odot}\mu_o$$
$$A = \exp(-\tau/\mu)\exp(-\tau/\mu_o)$$
$$B = \exp(-\tau/\mu) H^{-1} \int_H L_o(\vec{r}', \hat{k}) \cos\theta_i d\Omega_i$$

The terms C, a, and b represent the effect of an average albedo, a, of the nearby surroundings. The term 1/(1 - ab) where b is a measure of the backscatter of the atmosphere to upwelling radiance from the surface comes from a geometric series accounting for multiple reflection events, and may be thought of as an increasing of the irradiance of the surface over the zero-albedo case. C is a measure of the probability that a photon that has interacted with the surface in the vicinity of $\vec{r}'$ is scattered upward in such a way that it passes through $\vec{r}$ in the direction $\hat{k}$. Both a spatial and hemispherical averaging is involved in estimating a, so a represents some ground distance weighting from $\vec{r}'$.

Information about the scene at $\vec{r}'$ is contained in ρ'_λ and its hemispherical incoming radiance average

$$\bar{\rho}'_\lambda = \frac{\int_H \rho' L_o(\vec{r}', \hat{k}_i) \cos\theta_i d\Omega_i}{\int_H L_o(\vec{r}', \hat{k}_i) \cos\theta_i d\Omega_i}$$

For a 23 km visibility, 550 μm wavelength and a solar zenith angle of 30°, B is approximately 37% of A and C is approximately 42% of A. If the surface is, in fact, a uniform Lambertian surface of reflectance R ($\rho'_\lambda = \bar{\rho}'_\lambda = a/\pi = R/\pi$), then the ratio of target-derived radiance at $\vec{r}'$ to total scene-derived radiance is 1.37/1.79

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storage elements cause finite rise times to step changes in detector irradiance; thus any given sample of the continuous signal contains information of the recent past, resulting in an angular smear of the IFOV. In sensor arrays, there is a smear simply caused by the integration of along-track radiance during the time between dumps of CCD charge. In Thematic Mapper the detector, preamp, and filter effects dominate the optical effects on IFOV definition. (5) In typical integration times of a few milliseconds, along-track smear in CCD's will be on the order of 10 meters.

In summary then, the scanner or array takes an optically fuzzy IFOV sample of the photon flux or radiance at the sensor aperture and smears this sample either across-track through energy storage inherent in the detector and electronics or along-track through finite exposure time of a moving integrating detector.

Geometric aspects of remote sensing have not been as strongly pursued by the community of researchers and appliers as the multispectral identification of scene elements through pattern recognition. Consider the across-track geometry alone:

$$\theta'_n = \sin^{-1} \frac{(r_o+E)\sin a/r_o}{\sqrt{(r_o+A)^2+(r_o+E)^2-2(r_o+A)(r_o+E)\cos a/r_o}}$$

where r_o = nominal Earth radius at sensor nadir
A = altitude of sensor above Earth
E = elevation of terrain
a = arc length along a sphere of radius r_o, nadir to observation point

At 90 km arc length from nadir and 705 km altitude the elevation sensitivity of θ'_n is 0.1975 microradian/meter of elevation. A one-pixel angular shift at this distance from nadir is caused by 60 m elevation, 120 m elevation, and 215 m elevation for SPOT panchromatic, SPOT spectral, and Thematic Mapper respectively. If mapping to a plane tangent to the nadir point, or mapping to an oblique transverse Mercator cylinder tangent to the suborbital track, even for zero elevation, for a=90 km arc length the intersection of either the plane or cylinder and the line of sight is 84 m short of 90 km, while the Mercator projection would be 6 m longer than 90 km. Thus even for a zero elevation scene on a sphere the planar mapping scheme employed could cause a variance of several pixels. Of course, spherical surface mapping corrections could be easily made on-board or on-ground. The primary problem of mapping is elevation even in the case of perfect knowledge of the orbit and the precise pointing of the telescope at the sampling moment.

The most serious cause, in my opinion, of geometric difficulties in remote sensing data is the system deviation from ideality: platform attitude changes, scan mirror velocity deviations, and system mechanical vibrations. Thematic Mapper will hold nadir orientation within ±0.01° bounds. SPOT has ±0.15° bounds and the following limits on angular rates in various parts of the frequency spectrum:

Slew Rate μrad/sec \ f(Hz)	2	0.05-2	2
Roll	7	4.4	3.5
Yaw	7	5.2	3.5
Pitch	7	10.5	7

Awareness of these difficulties arose soon after the first MSS data became available (6), and are currently under study today. The principle question in correcting for sensor/platform-induced errors is who should do it and how. If corrections are to be made by the user then system state data must be provided in the form of attitude measures, scan mirror velocity, orbital track position, sensor calibrations (for radiance corrections), and a good model of the sensor system will be required as well. This will require a fair amount of sophistication and software development on the user's part. If it is to be done in dedicated processing units such as SPOT IMAGE, where such sophistication can be expected, the cost will obviously be passed on to the user.

The major changes that I sense in processing techniques for the '80's will center around the question of how much infusion of hard physical sensor/platform data, ground elevation data, and atmospheric models will be optimum with respect to a given remote sensing user task. The data magnitudes associated with Thematic Mapper pixel size and SPOT pixel size are nearly an order of magnitude beyond MSS, and there is very limited experience in the community with image plane arrays. Striping effects have been noticeable in MSS; the problem will increase by two orders of magnitude with several thousand detector arrays. Atmospheric effects in the SWIR bands of Thematic Mapper at satellite altitudes viewing will be unfamiliar. Reduction of mixed pixel effects may well be balanced against the increased pixel-to-pixel noise due to fine-grained or high spatial frequencies in scene ρ'_λ. I have a strong feeling that we have gone about as far as we can go with the giant leap from ground truth to pattern recognition without using knowledge available of the intervening system including geometric complexities.

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