Optics for the Satellite Remote Sensing Systems

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Abstract

Examples of advanced digital electro-optic imaging systems for the satellite remote sensing applications are introduced including multispectral focal plane assembly for newly proposed 1-m spatial resolution capability.

Introduction

The most secretive application areas of high performance electro-optic imaging systems have been in the strategic and tactical search and survey missions. Now the world has been changing rapidly to the point where a lot of space technologies of cold war days can be converted to information and knowledge businesses if not for national pride and security. Currently the most active commercial remote sensing satellite systems are the French SPOT and the US LandSat with 10-m and 30-m panchromatic resolutions respectively with less resolutions for multi-spectral imageries.

In Korea, the "Uri-Byul" team at KAIST has been operating two micro-class imaging satellites (< 100kg) for sometime and is currently planning satellites of 15-m and 5-m spatial resolution in near future. Also under development is the national R&D satellite system, KOMPSAT, under the management of KARI as a small satellite class (<500kg) with 10-m capability like the SPOT. KOMPSAT also contains a low resolution camera system for multispectral oceanographic monitoring and other scientific payloads.

The most dramatic proposition at this time, however, has been the 1-m resolution commercial remote sensing satellite (CRSS) system proposed by Lockheed Martin with US government approval. The optical sensor assemblies (OSA) of the 10-m and 1-m systems will be reviewed.

Basics

Assuming a diffraction-limited system, the spatial resolution of a satellite optical imaging system depends upon the diameter of the imaging optics, orbit altitude, field-of-view, spectral bands, spacecraft attitude and position accuracy, focal plane imaging array and electronics etc. The conventional systems used to have films stored in capsule as the recording media which can be ejected from a satellite and retrieved in the air for the ground wet processing. Most of the current systems utilize electro-optic focal planes of proper CCDs and associated electronics for digital imageries and processing. Tables 1 and 2 summarize typical trades for mission related parameters.

Fig. 1 illustrates a perspective view of the CRSS satellite with indications of OSA subsystems.

* Optical Telescope Unit: optics, metering structure, focus actuators and thermal control heaters.

* Focal Plane Unit: CCD focal plane, analog video processing and A/D converters.

* Digital Processing Unit: data formatting, bandwidth compressing, output to high speed storage unit.

* Power Supply Unit: power conditioning, switching for OSA electronics.

Fig. 2 shows the schematics of the optical telescope with 70cm aperture and 10m focal length covering between 0.45 μm - 0.9μm. The primary mirror (PM) has a concave ellipsoid of 70cm diameter made of ULE frit-bonded with two face sheet. The secondary mirror (SM) is a convex hyperboloid of 15.37cm diameter solid ULE and equipped with a focus-drive mechanism for long-term drift. The tertiary mirror (TM) is an off-axis portion of a solid ULE concave ellipsoid with 15.6cm x 9.18 cm.

The field stop (FS) is a flat black slit plate with knife edges positioned at intermediate image. The aperture stop (AS) is a flat black .ound mask with knife edges positioned a system exit pupil. Both stops are used for stray light control.

Panchromatic and Multi-Spectral Imaging(MSI)

The Fig.3 and Table 3 indicate the focal plane arrays and characteristics for both panchromatic and multi-spectral imaging. Typical areas of applications for MSI data can be grouped in the following categories.

Pan-sharpening

The MSI data can be used to add color to the simultaneously collected higher resolution panchromatic data. The two data sets will be "fused" using an algorithm which preserves the vast majority of the information contained in the multispectral data. The results will be either a natural color composite (using the first three MSI bands as RGB) or a false color IR composite (using the last three MSI bands as RGB) image. The fused imagery will possess all of the panchromatic data in addition to the color (multispectral) information of the MSI.

Vegetation Assessment

The MSI spectral bands are designed to follow the first four spectral bands of the LandSat Thematic Mapper (TM) sensor. The width and placement of these spectral bands were originally selected to maximize their sensitivity to vegetation. The third and fourth (red and near IR) bands are commonly used to generate ratio imagery (normalized vegetation and the concentration of green plants (chlorophyll) within each pixel.

Concentrations in chlorophyll, particularly changes in concentrations (as mapped on ttwo images collected at different times) can be used to analyze a variety of important phenomenon: such as crop/forest stress, pollution stress, harvesting patterns of areas, movement of heavy equipment over vegetated terrain, agricultural practices, etc.

Pollution Monitoring

In most cases, the presence of pollution can be detected directly. However, the MSI can be used to detect the secondary and tertiary effects of the pollution.

Using imagery from two or more dates the MSI can be used to monitor vegetation stress that might be caused by the presence of the pollution. If the pollution is in river, lakes or coastal areas, the MSI can be used to detect suspended sediments, algae blooms and other phenomenon that might be associated with the pollution and thus monitor the distribution of the polluting substances.

Iron Oxide Detection

The first and third spectral bands (blue and red) can be used to detect the presence of iron oxides. Mineral containing highly oxidized iron (hematite, limonite, jarosite and others) absorb strongly in the blue and reflect in the red. Ration imagery generated from these two bands can be used to map the distribution of iron oxide rich minerals.

Concentrations of iron oxide rich minerals (gossans) commonly associate with a number of base metal mineral deposits. Mapping gossans distributions can be a useful tool in the geologic exploration for these , as well as other, economic mineral deposits.

Bathymetry

as a ray of light penetrates a column of water, it is attenuated (absorbed) by interaction with the water molecules and suspended particulate matter. The depth of penetration of the four individual spectral bands are inversely proportional to the bands' wavelength. Therefore, the first band (blue) has the deepest penetration and the fourth band (near IR) has the shallowest.

Given a reflective bottom sediment (light color sand or mud), the visible light will penetrate the water column, reflect off of the bottom and reemerge at the water's surface. The intensity of the light that emerges (and thus the intensity of the light measured by the satellite) is inversely proportional to the depth of the water column. In other words, the deeper the water, the more the attenuation of the light, and thus the less the intensity of the measured light reaching the satellite.

I clear water, with a strongly reflective bottom material, the first spectral band can penetrate (and reemerge) to water depths of up to 90m. In such areas, as the water depth lessens the intensity of the first band, as measured at the satellite, increases. Thus the greyscale image of the first spectral band can be used to map the distribution of water depths (bathymetry).

There are several factors that can effect the usefulness of this technique. Errors can be created by changes in bottom reflectance, presence of sub aquatic vegetation, and presence of suspended sediments. However, even in the presence of these limitations, this technique can be a useful tool to map coastal areas.

Water/Land Discrimination

The fourth spectral band (near IR) is strongly absorbed by water. This causes the radiance values of band 4 over water bodies are extremely low. The fourth band can therefore be used to clearly distinguish between land and water.

The ability to distinguish between water and land is useful for automatically creating shoreline maps of ocean and lake areas, definition of wetland areas, definition of flooded areas, etc.

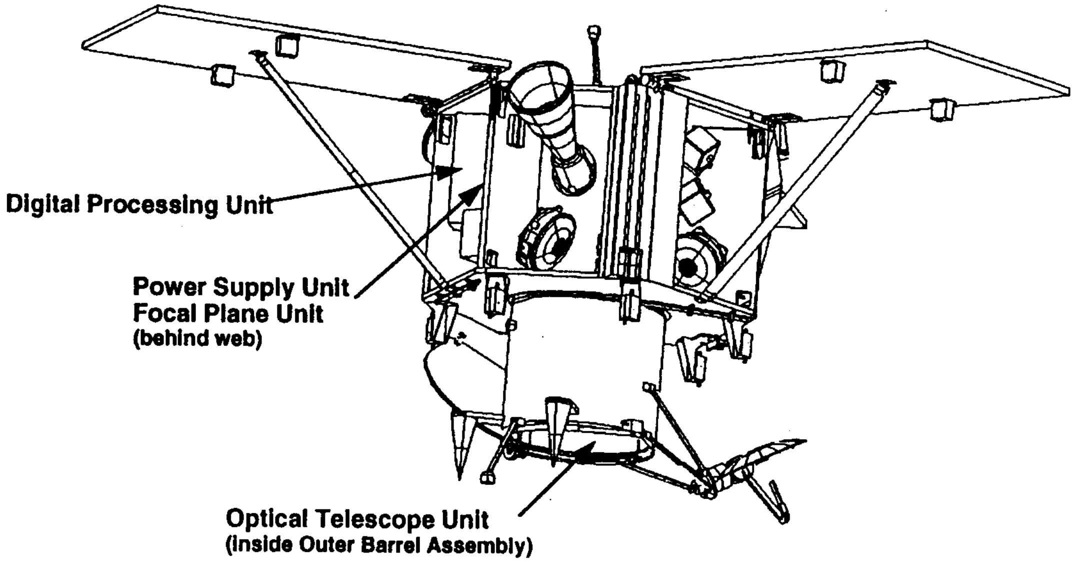

Figure 1. Perspective View of the CRSS Satellite

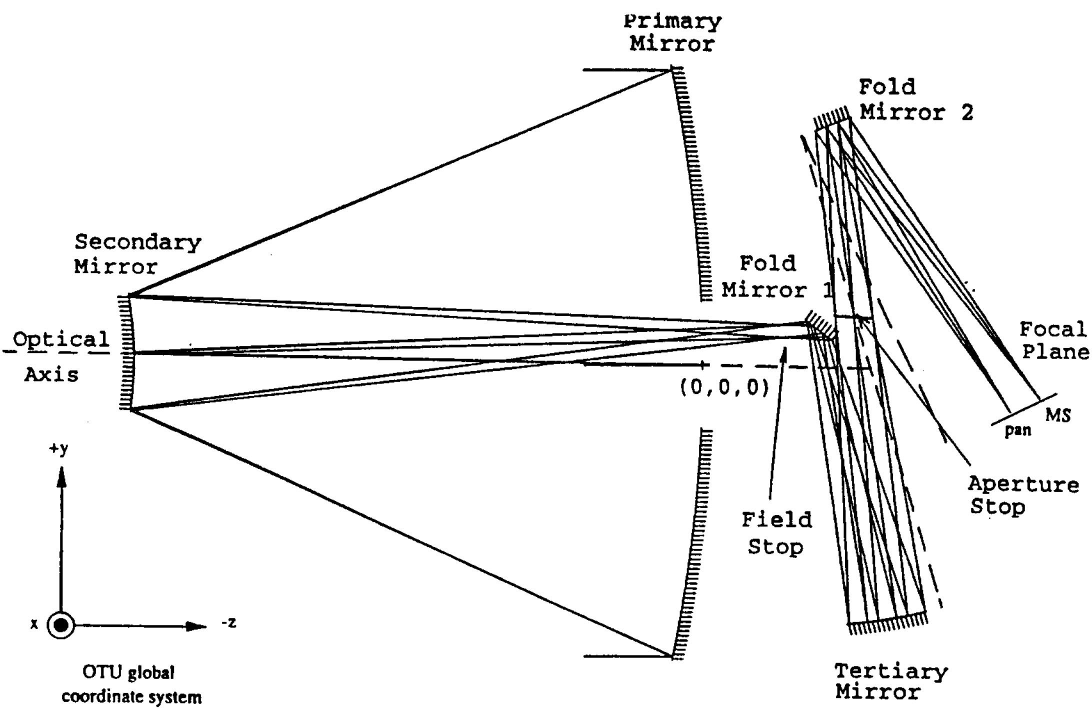

Figure 2. Schematics of the Optical Telescope

Mission Category:	GEOSYNCHRONOUS MISSIONS (GEO)	SPACE SURVEILLANCE & INSPECTION	LOW-EARTH-ORBIT MISSIONS (LEO)
Mission 1	Theater & Strategic Warning SWIR, 600 m resolution	Space Surveillance Visual band, 25 m resolution	Visual-band Surveillance Visual, 3 m resolution
Mission 2	DMSP Augmentation Visual to LWIR bands 300 to 1200 m resol'n.	Space Inspection Visual band, 10cm resolution	IR Surveillance MWIR to LWIR bands 8 to 25 m resolution
Mission 3			Oceanographic Mapping & Sensing, Visual & MWIR, 3 to 12 m resolution
Mission 4			IR Mapping LWIR, 25 m resolution
Orbit Altitude; Range	35800 km; 42000 km	various altitudes, as needed; 4000 km (surv.) & 40 km (insp.)	500 km; 735 km
Coverage	20° diameter, 3° swaths 20 s revisit (2 s theater)	3° swath scanner (surveillance) 0.16°-square starer (inspection)	≤ 13.6° swath (119km), ≥ 4 s update
Scan rate, °/s	8 (data), 10 (slew)	3 (surveillance data), 10 (slew)	4 (data), 10 (slew)
Wavebands, μm	0.45-1.0, 2.7-2.95, 3.4-3.9, 4.2-4.45, 10.6-11, 11-12	0.45-1.0 (visual only, objects must be sunlit)	0.45-1.0, 0.46-0.48, 0.50-0.52, 3.4-3.9, 4.6-4.8, 8.5-9.0, 10.6-11, 11-12
Focal Plane Array array size, detector material & (size, μm)	Warning & DMSP Augm., f/7: 3299 x 4 HgCdTe, (50) DMSP Augmentation, f/7: 9163 x 2 Si CCD, (18) 1649 x 6 HgCdTe, (100)	Surveillance, f/7: 9163 x 10 Si CCD, (18) Inspection, f/15: 1024 x 1024 Si CCD, (18)	Visual & Ocean Mapping, f/7: 3054 x 6 Si CCD (18) IR & Ocean Sensing, f/ 7: 3299 x 4 HgCdTe (50) 1649 x 6 HgCdTe (100)

Table 1. Mission vs. Satellite Parameters

BAND	WAVELENGTH, μm	MISSION TYPES	PURPOSE
1	0.45 - 1.0	VISUAL SURVEILLANCE, INSPECTION, WEATHER	VISUAL MAPS (panchromic), DAYLIT CLOUDS
2	0.46 - 0.48	OCEANOGRAPHIC	BLUE - OCEAN DEPTH
3	0.50 - 0.52	OCEANOGRAPHIC	GREEN - DEEP WATER DEPTH
4	2.70 - 2.95	WARNING	MISSILE PLUME TRACKING
5	3.4 - 3.9	OCEANOGRAPHIC, WEATHER, IR SURVEILLANCE	SEA WAVES & TEMPERATURE, IR MAPPING, NIGHT CLOUDS
6	4.2 - 4.45	WARNING	MISSILE PLUME TRACKING, LATER STAGES
7	4.6 - 4.8	OCEANOGRAPHIC	LARGE SHIP DETECTION
8	8.5 - 9.0	IR SURVEILLANCE	LWIR MAPPING, TERRAIN, SHIP DETECTION
9	10.6 - 11.0	WEATHER	CLOUD HEIGHT, IR MAPPING
10	11.0 - 12.0	WEATHER	WATER VAPOR CORRECTION, LAND TEMPERATURE, IR MAPS

Table 2. Multi-spectral Missions

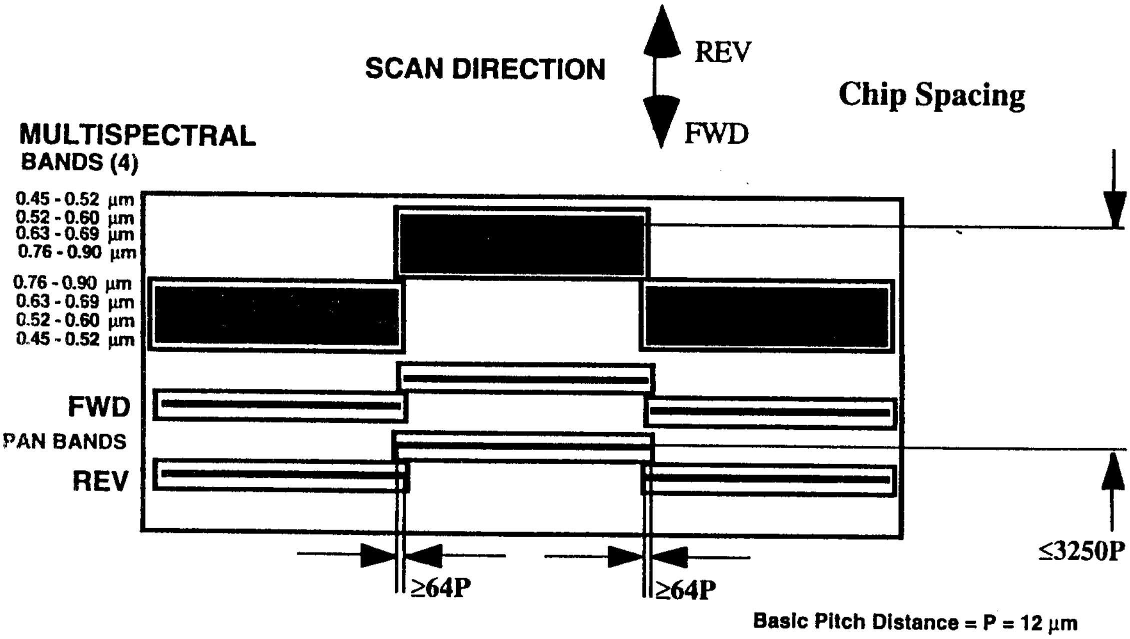

Figure 3. Focal Plane Array Layout

Wavebands	Panchromatic Band	Multispectral Bands
	0.45μm to 0.9μm	Band 1 0.45 to 0.52 μm Band 2 0.52 to 0.60 μm Band 3 0.63 to 0.69 μm Band 4 0.76 to 0.90 μm
No. of Pixels/Line	13,816 net/14,208 gross	3,454 net/3,552 gross
Detector Size	12μm Square	48Mm square
TDI Stages	10, 12, 18, 24, 32	N/A
Scan Rate	6,500 lines/sec	1,625 lines/sec
Data Processing	Simultaneously 24 Pan. + 12 MS Channels	
Quantization	11 Bit	11 Bit
Max. WB Data Rate	300 Mbps (Pan + MS)	

Table 3. Focal Plane Design Base