

Chapter 12

MULTISPECTRAL IMAGERY

Multispectral Imagery (MSI) is steadily growing in popularity within DOD as a digital means for mission planning, thermal signature detection and terrain analysis. It is frequently used as a map substitute when standard Mapping, Charting and Geodesy (MC&G) products are outdated or inadequate. The ability to record spectral reflectances in different portions of the electromagnetic spectrum is the main attribute of MSI, which can be useful in a number of applications. This chapter addresses some of the theory and applications related to MSI.

OVERVIEW

In recent years, an increasing share of training and equipment resources have been dedicated to field users of MSI, such as US Marine Corps (USMC) and US Army (USA) topographic units. US Air Force (USAF) and US Navy applications of MSI have also been gaining acceptance, supporting image mapping, mission planning, navigation and targeting. These products and others have been widely used in operations such as DESERT SHIELD/DESERT STORM, support to activities in the former Yugoslavia, Somalia, Haiti, many "special" operations and in a large number of training exercises.

MSI provides information not available by only exploiting the visible region of the electromagnetic spectrum. It typically provides such things as terrain information over broad areas in an unclassified format. These attributes make MSI convenient to share with personnel and organizations that are not usually privileged with controlled information from "national" assets. Multinational forces, news media and civil authorities can all share the benefits of MSI.

MSI is currently available from commercial sources for Government or private users. Copyright law and restrictions on sharing data protect almost every image (except older imagery with little commercial value). The National Imagery and Mapping Agency (NIMA) is the executive agent for the purchase of commercial satellite imagery within

DOD. Imagery purchased through NIMA was bought with a DOD-wide distribution license and can be copied and distributed freely within DOD, without copyright constraints. The Commercial Satellite Imagery Library (CSIL) is an archive of all DOD purchased commercial satellite imagery. The CSIL is maintained by the Defense Intelligence Agency (DIA) for NIMA and available electronically on the Intelink Network. Further information on how to order CSIL products can be obtained by visiting the list of NIMA/CIP & CSIL Websites provided in the references at the end of this chapter.

Many DOD organizations use MSI and are capable of production capabilities or are knowledgeable of where to obtain support for operations and exercises. Historically, MSI users who develop a support network along the lines of their most important applications generally fare better in their use of MSI. Though this type of loose organizational structure is anathema to many DOD leaders, it is this informal network of users that has been largely responsible for the successes of MSI and its applications.

HISTORY

Remote sensing was used by the military in World War II, Korea and Vietnam for tactical and strategic reconnaissance and surveillance. MSI is a direct outgrowth of the operational success of Color Infrared (CIR) imagery of the 1960's. In Vietnam, CIR imagery was frequently used to distinguish artificial

features, such as camouflage, from a background of natural vegetation. The successes of this and other applications of CIR imagery fueled practical consideration of imaging devices that could not only exploit the IR (Infrared) spectral region, but could also discriminate between blue, green, red and near IR regions of the electromagnetic spectrum. The electromagnetic spectrum extends from the short wave cosmic ray region to the long wave TV and radio wave region received at home. Technology of the early 1970's led to the development of a new sensor, the 4-band Multispectral Scanner (MSS), which was used on the original Landsat 1 (see below). This sensor digitally imaged four spectral regions (blue, green, red and near infrared). Today, MSI covers the portion of the electromagnetic spectrum from the ultraviolet region through the infrared region.

Remote sensing and the MSS sensor offer other advantages besides being able to image in specific spectral regions. These include the ability to "capture" images digitally, transmit the imagery electronically, store the information on magnetic media and process the digital information using computers. Since the information is captured by the sensor as a matrix (rows and columns) of numbers, computers provide a perfect means to sift through the combinations of bands and present the information on a computer monitor. The information can be easily manipulated to support specific analysis. An image can be merged electronically with other information, such as slope or land cover data, allowing analysts to derive greater information from the imagery.

In the early days of space-borne multispectral imaging, computers were only readily available at fixed sites within DOD and at large civil institutions such as universities. Therefore, much of the early work performed with MSI was conducted using "hardcopy" (paper or

film) products derived from the digital information provided by the sensor. These digital-film techniques initially were very expensive, but as the cost of computers fell and versions of image processing software which could run on most types of operating systems became available, many new MSI applications found markets within military units, other



DOD agencies and the civilian sector.

Fig. 12-1: ERTS-A in Checkout

The first satellite to use MSI for Earth remote sensing was the Earth Resources Technology Satellite-A (ERTS-A), (**Fig. 12-1**) which was later renamed Landsat 1 by the National Aeronautics and Space Administration (NASA). It was the first in a series of satellites designed to provide repetitive global coverage of the Earth's landmasses. Landsat 1 was launched in July 1972 and finally ceased to operate in January 1978. The second satellite in the series was launched in January 1975. Four additional LANDSATS have been launched in 1978, 1982, 1984, and 1999 (LANDSAT 3, 4, 5, and 7 respectively). Landsat 5 is operating beyond its design life. LANDSATs 1, 2, 3 and 4 are no longer operational.

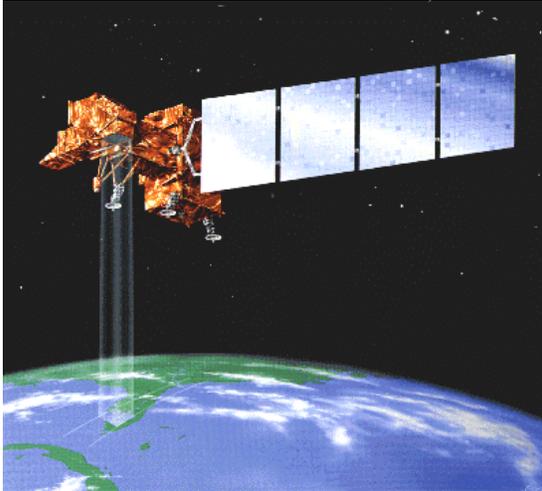


Fig. 12-2: Landsat 7

LANDSAT 6 also was launched but failed to successfully achieve orbit in October 1993. LANDSAT 7 was launched on April 15, 1999 (Fig. 12-2). One of the LANDSAT 7 improvements is the Enhanced Thematic Mapper Plus (ETM+), which will produce data in six spectral bands at 28.5 meter spatial resolution, one panchromatic band with a 15 meter spatial resolution, and one long wave IR band with a 60 meter spatial resolution.

NASA was responsible for operating the LANDSAT satellites through the early 1980's. In 1985, as part of an effort to precipitate commercialization of space, LANDSAT was commercialized and all rights became the property of the Earth Observation Satellite Company (EOSAT). However, in November 1996, Space Imaging and Lockheed-Martin reached an agreement to purchase EOSAT; now referred to as Space Imaging EOSAT.

Landsat 7 was developed as a tri-agency program between NASA, NOAA, and the USGS. NASA was responsible for the development and launch of the satellite as well as the development of the ground system. NOAA provided its operational expertise to the developers of the ground system while USGS is responsible for receiving, processing, archiving and distributing the data.

Earlier LANDSAT satellites carried the MSS, the most capable sensor on LANDSATs 1, 2 and 3. The sensor suite

used on LANDSATs 4 and 5 included MSS, but a more capable sensor called the Thematic Mapper (TM) was added to increase the spectral and spatial capability of these systems. The TM sensor captures information in seven spectral bands:

- Band 1 - .42-.52 microns (blue) used for such things as soil, vegetation and coastal water mapping
- Band 2 - .52-.60 microns (green) used for such things as depicting green reflectance of vegetation
- Band 3 - .63-.69 microns (red) used for such things as differentiating vegetation based on chlorophyll absorption
- Band 4 - .76-.90 microns (near IR) used for such things as vegetation and biomass surveys
- Band 5 - 1.55-1.75 microns (short wave IR) used for such things as to sense vegetation moisture and snow/cloud reflectance differences
- Band 6 - 10.4-12.5 microns (long wave IR) used for such things as thermal mapping
- Band 7 - 2.08-2.35 microns (short wave IR) used for such things as determining vegetation moisture and depiction of minerals (based on hydroxyl ions) for geological mapping

Another satellite whose product has enjoyed broad acceptance within DOD is the French satellite called "SPOT" (Satellite Pour L'Observation de la Terre). SPOT satellites carry two High Resolution Visible (HRV) sensors with the capability of collecting imagery in either three spectral bands (green, red and near infrared regions) or one panchromatic band. SPOT 4, the newest satellite in the line (Fig. 12-3), added a fourth short wave band to its MSI. MSI bands are collected at 20 meter spatial resolution while the panchromatic band is collected at 10 meter spatial resolution. The SPOT data most frequently used by the DOD is the panchromatic imagery. SPOT sensors have the capability to scan 27 degrees

off-nadir, allowing for repeat coverage of an area every two to twenty-six days, depending where on the earth's surface the image is being taken. SPOT's panchromatic mode also yields an image with a better spatial resolution (see the "Theory" section for a complete discussion of resolution).

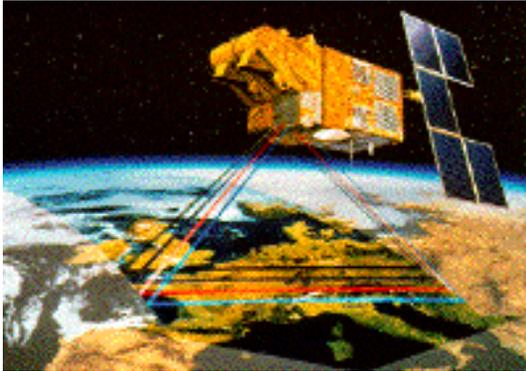


Fig. 12-3: Spot 4

By the mid-1980's, India was well on its way to developing the Indian Remote Sensing Satellite (IRS). IRS-1A was launched in 1988, and an identical follow-on satellite, IRS-1B, was launched in 1991. Both satellites are equipped with sensors that acquire multispectral data comparable to that available from LANDSAT and SPOT satellites. In December 1995, the IRS-1C was launched. IRS-1C has enhanced capabilities in terms of spatial resolution, with a 5 meter panchromatic band and a wide-field capability for large area monitoring. IRS-1D, identical to IRS-1C, became India's newest imaging satellite with its launch in September 1997 (Fig. 12-4).

RADARSAT, a Canadian satellite, was launched in 1995 and is equipped with an advanced Synthetic Aperture Radar (SAR). A SAR is a powerful microwave instrument that transmits pulsed signals to Earth and then processes the returned signals. SAR-based technology provides its own illumination, enabling it to see through clouds, haze, smoke and darkness, thus providing images of the Earth in all weather conditions, at any

time. This ability to actively image in all weather conditions offers a much needed alternative during periods when cloud cover prevents imaging with a passive sensor (sensors that do not provide their own illumination) such as LANDSAT, SPOT and the IRS satellites. RADARSAT provides the first routine surveillance of the entire Arctic region and accurately monitors disasters such as oil spills, floods and earthquakes. RADARSAT provides imagery that is of exceptional value in supporting a wide



range of DOD and civilian applications.

Fig. 12-4: IRS-1D at liftoff

The first European Remote Sensing Satellite (ERS-1) was launched in July 1991 (Fig. 12-5), with a second (ERS-2) launched in April 1995. The ERS satellites use SAR microwave techniques to acquire measurements and images, regardless of cloud and sunlight conditions. ERS sensors have the capability to measure echoes from ocean and ice surfaces, sea surface and cloud-top temperatures and provide information about ocean waves (length and direction). The ERS mission is oriented primarily towards ocean and ice monitoring, which is particularly important since oceans cover approximately three-quarters of the Earth's surface and have a dominant effect on the global climate system.



Fig. 12-5: ERS-1 at Checkout

THEORY

The electromagnetic spectrum (Fig. 12-6) provides the medium exploited by Multispectral Imagery. Regions of the spectrum are selected for coverage by sensor bands to optimize collection for certain categories of information most evident in those bands. Multispectral bands in the near infrared (NIR) region and shortwave infrared (SWIR) regions are used to discriminate features that are

not visible to the human eye. Important features like mineral and oil-bearing rock structures are more easily detected using data collected in these longer wavelength IR bands. For instance, actively growing vegetation can be easily separated from many other features in the near infrared (NIR) region because the chlorophyll in the plants is reflected to a far greater extent in the NIR band than any other feature return. Emitted or thermal radiance in the midwave and longwave regions is also detectable by passive spectral sensors. Heat sources such as industrial processes and power-generating facilities generate IR energy that are detectable from both aircraft and satellite sensors sensitive to these spectral regions.

Multispectral sensors are designed to support applications by providing bands that detect information in specific combinations of desirable regions of the spectrum. Figure 12-7 illustrates the utility of spectral regions.

The number and position of bands in each sensor provide a unique combination of spectral information and are tailored to the requirements the sensor was designed to support. For example, LANDSAT TM, with bands in both the near IR (chlorophyll detection) and shortwave IR (wetness) are capable of measuring the health of vegetation.

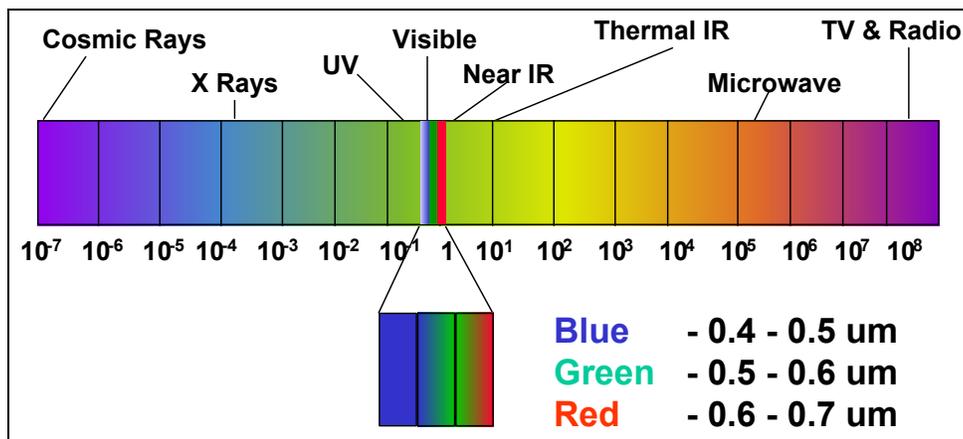


Fig. 12-6 Electromagnetic Spectrum

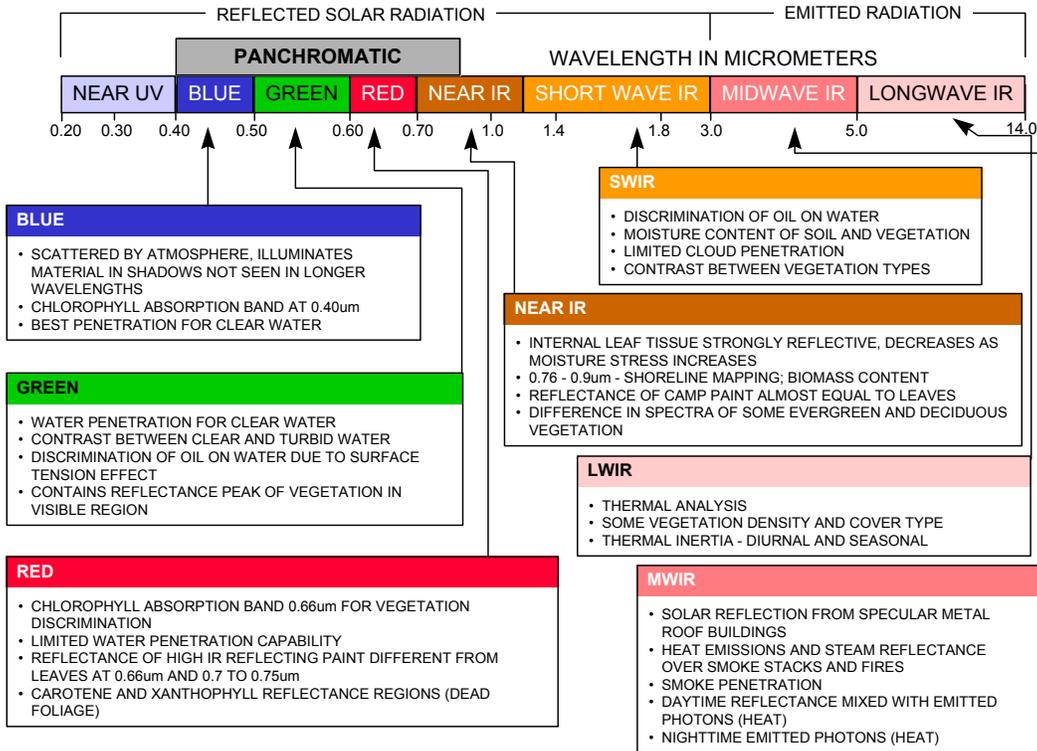


Fig. 12-7. Spectral Regions

Numeric values (also called brightness values) are recorded as a means of identifying the brightness associated with the light reflected from different material in each spectral band.

Figure 12-8 illustrates the difference in reflectivity of materials across a portion of the electromagnetic spectrum,

matched against four LANDSAT bands. In this example, grass and artificial turf show similar reflectivity properties across this portion of the spectrum, except for LANDSAT band 4 (NIR).

Choosing the correct position across the spectrum optimizes the ability to discriminate between various materials. In

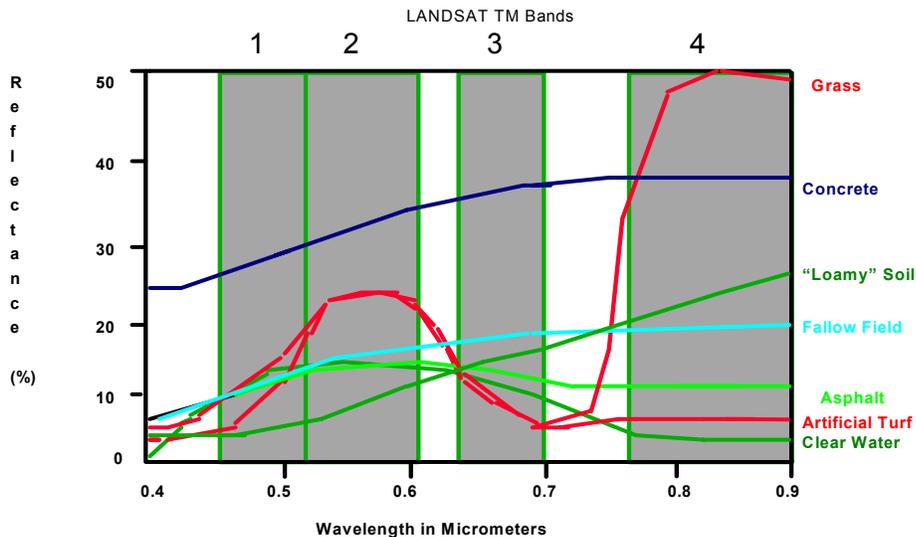


Fig. 12-8. Spectral Responses and Band Positions

this example, band 4 should be used to discriminate between grass and artificial turf.

A spectral collection system records electromagnetic (EM) radiation. The EM radiation detected by the collection system may be solar reflected energy or thermal (photons) emitted by an object. EM radiation may be thought of as a wave, having an associated wavelength measured from wave peak to wave peak.

Figure 12-9 depicts how wavelengths are measured between wave peaks. Shorter wavelengths have shorter distances between wave peaks; longer wavelengths have greater distances between wave peaks. The amount and type of radiation reflected are directly related to an object's surface chemical and physical character-

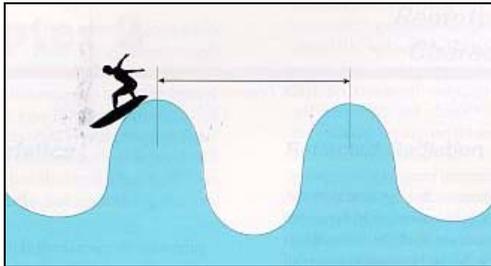


Fig. 12-9. Wavelength Measurement

istics.

A portion of the reflected EM radiation exits through the atmosphere and is received and recorded by the satellite. Those areas of the atmosphere that allow for transmission of EM radiation are known as atmospheric windows. In other areas of the electromagnetic spectrum, the atmosphere itself reflects, absorbs or scatters too much energy (because of particulate matter, aerosols and water vapor) blocking the passage of EM radiation, making it impossible for the sensor to obtain measurable information. This blocking effect is called "atmospheric attenuation." Remote sensing instruments are designed primarily to record information passed through these atmospheric windows. **Figure 12-10** demonstrates this concept.

This reflected energy is received by the sensor array in the form of individual brightness values or picture elements

(pixels). In a digital system, a pixel represents an area on the Earth's surface. The SPOT panchromatic sensor has pixels that are the average of the light reflected from a 10 meter by 10 meter area (10m x 10m) on the ground. Therefore, SPOT panchromatic imagery can be said to have 10 meter pixels. LANDSAT TM has a 28.5

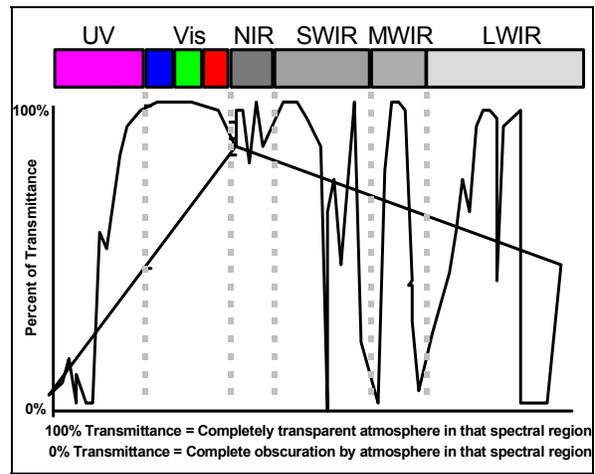


Fig. 12-10: Atmospheric Windows

meter pixel size.

Spatial resolution is another way of stating the size of pixels for a digital system. Pixel size is a direct indicator of the spatial resolution of the sensor because pixels are the smallest elements that can be detected by the sensor. Spatial resolution is a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor. More simply put, it is the smallest separation between two objects on the ground that can be detected as a separate object. This type of resolution is related to the Ground Sampling Distance (GSD) of a system. GSD is defined as the distance between centers of pixels or in other words, the centers of areas sampled on the ground. An image from the LANDSAT TM sensor, which has a GSD of 28.5 meters, will not normally allow for detection of an object that is five meters. With current systems, resolution is usually referred to in meters and each pixel will sample a square area on the ground in terms of meters.

Spectral resolution refers to the spectral position and bandwidth of the bands

a sensor collects. The LANDSAT TM sensor could be said to have moderate spectral resolution (seven relatively wide bands) in contrast to the SPOT panchromatic sensor that has poor spectral resolution due to its single very broad band. Generally, the narrower the band and the higher the number of bands, the better the spectral resolution.

A temporal resolution refers to the time it takes an imaging system to return to an area to collect another image. It is essentially a satellite's revisit time. All imagery collected provides an electronic "snapshot" of a particular area and moment. To understand changing conditions of a particular area may require a number of images.

Temporal resolution must be considered when ordering imagery from any source. If a satellite is not over a requester's area of interest when needed, you must wait until the satellite's next revisit time. If the area is cloud-covered during imaging, the user may have to wait for another imaging opportunity. If using LANDSAT 5, the revisit time would be 16 days (in conjunction with LANDSAT 7, it is cut to 8 days).

Radiometric resolution refers to the sensitivity of a spectral band. LANDSAT, SPOT and IRS detect and record an image in each band in 256 levels of brightness (an 8-bit image). One multispectral imager aboard the TIROS weather satellite, called the Advanced High Resolution Radiometer (AVHRR), collects imagery in 1,024 levels of brightness (a 10-bit image). Therefore, TIROS is said to have greater radiometric resolution than LANDSAT, even though the spatial resolution of this sensor is significantly less than that of the other.

Viewing geometries for MSI satellites are available in two varieties: nadir viewing and off-nadir/directional viewing. Nadir refers to the point on the planet directly below the satellite. Nadir imagers look straight down at the Earth and have no ability to look at objects away from nadir under any deliberate circumstance. Such systems are excellent for providing

images that have minimal geometric distortions. Distortions in nadir imagers are normally due to Earth's curvature and space environmental effects that disrupt the stability of the satellite, introducing pitch, yaw or roll. LANDSAT, being a nadir imager, is restricted to imaging along predictable tracks, or "paths," according to orbital characteristics and the field of view of the sensor.

Directional systems have the ability to view the Earth away from the ground track of the satellite's orbit or, "off-nadir." SPOT is an off-nadir imager with the ability to image up to 27 degrees across track (side-to-side) in each direction. The opportunities presented by off-nadir systems include a reduction in the amount of elapsed time between the periods when the satellite can image the same point on Earth, referred to as "revisit time" or temporal resolution, and the ability to produce stereo views. However, due to the effect of imaging across a spherical surface, users of off-nadir imagery pay the price of higher geometric distortions within the image.

Orbital characteristics have direct influence on the imaging capacity of all spaceborne sensors. Systems such as LANDSAT, SPOT and IRS are dependent upon reflected energy from the sun that makes them effective imagers only during periods of sunlight. In addition, the usefulness of MSI is enhanced for many applications when the images are captured at specific sun elevation angles. Therefore, commercial imaging satellites are typically placed in an orbit described as a "sun-synchronous orbit," allowing the satellites to predictably collect imagery in specified sun angles. Each satellite orbits with specific times established for equatorial crossing; a feature that allows reliable prediction of imaging times at points along its ground track.

These satellites are also dependent upon maintaining a standard distance from the Earth's surface in order to maintain a consistent spatial resolution. If the satellite were to drift higher or lower in relation to the Earth's surface, the spatial resolution of each image would change as

well, reducing the usefulness of the images to users who depend upon consistency. “Circular” or “low eccentricity” orbits are a necessity for imaging systems to ensure consistent spatial resolution. Each satellite is carefully placed in an orbit to meet the specifications of its sensor package.

Space environmental effects impact MSI satellites the same as they affect other satellites. Because they are in relatively low Earth orbits, they are particularly susceptible to the Earth’s atmospheric effects.

MILITARY APPLICATIONS

Although not a complete list, the following MSI applications are among the more commonly used by today’s military.

Analysis Images are among the simplest of MSI products, normally consisting of a natural colored image of the desired site. The image is minimally processed to reduce the production time and is constructed in pre-determined sizes according to need.

Context Images are similar to Analysis Images but are frequently produced in black and white to facilitate correlation with black and white high resolution images used by intelligence analysts. The purpose of Context Images is to provide a broad area perspective around a target.

Image Maps are a common application of Multispectral Imagery and exploit the broad-area coverage capabilities of MSI. An Image Map is nothing more than an image of the area of interest with a commonly understood grid overlaid. Typically, the images are rectified so that features on the Image Map correspond to features on a selected coordinate system and are in proper relationship to features on the Earth’s surface. The advantage of these products is that the user receives a literal image that requires little experience or training to use. These

images can portray the terrain in near-natural colors, with some enhancements applied to ease utilization by non-trained personnel. Image maps are most useful when topographic maps are not available or when used as supplements to older maps. MSI provides a means of rapidly updating older, out-of-date topographic maps with image maps that provide a current, broad-area, synoptic view of the area of operations. The maps are processed to user specifications in terms of color, size, map projections and scale.

Image Mosaics are produced from two or more products and made into one larger geographic area. Mosaics are produced by digitally “stitching” images together, usually for visual effect. Prior to “stitching,” images are pre-processed to ensure an acceptable match of brightness value ranges (histogram matching) and those bands selected for the final product appear visually similar.

Perspective Views are a combination of MSI and elevation data such as Digital Terrain Elevation Data (DTED) and Digital Elevation Model (DEM) (produced and maintained under the auspices of the NIMA). The two-dimensional MSI image is draped over the three-dimensional digital terrain data and processed to simulate a view of an area or target of interest from a given position, altitude, azimuth and distance.

Relocatable Target Graphics are developed from many sources of information including MSI. In this product, several inputs are combined and evaluated using geographic information system techniques to enable prediction of the movements of mobile targets. Elevation matrices are converted to slope and evaluated to determine places where mobility restrictions would prevent target movement. MSI data is thematically classified to further reduce the potential hiding areas. Known information about operating characteristics of relocatable mobile targets is included in the analysis to provide predictive movement informa-

tion. High-resolution imagery is used to evaluate areas too small to be identified through other processes.

The data is combined in a processing scheme to predict the movement of vehicles given a known point of origin and terrain factors revealed through the analysis of the above data. Graphics registered to a selected map base are then produced to indicate the probability of movement across the terrain. Both hard-copy and softcopy products are constructed in this manner, depending upon user requirements.

Stereo Imagery is used to create elevation matrices and is made possible by off-nadir imaging systems or, less frequently, by two images from a single nadir imaging system. Two images of the same ground area are captured from different points in space (producing a stereo view of the area) and software is used to establish a mathematical relationship between points that can be identified on each image. Elevation data is then extracted using specially designed software and placed in a file to be used as needed.

TERCAT (TERrain CATegorization) is a pseudocolor thematic image in which the MSI data has been classified into groups representing different terrain types and land cover. TERCATs are useful in displaying vegetation classes, soil types and hydrology. They also support the analysis of lines of communications (LOCs), avenues of approach, cover and concealment, landing and drop zones.

Terrain Analysis Products are emerging as an important MSI product, drawing upon the ability of MSI to “thematically classify” statistically similar brightness values representing various types of terrain occurring in the image. Land-cover types (vegetation, urban areas, water) and density information are locked in the spectral images awaiting extraction using a variety of automated techniques and human judgment. Although terrain analysis products derived from MSI are not as accurate as “objec-

tive terrain databases,” in most cases, they can be developed much more quickly and within acceptable tolerances for supporting many tactical and strategic activities.

HISTORICAL USE IN MILITARY OPERATIONS

Prior to DESERT SHIELD

Before DESERT SHIELD, MSI was generally treated as a dubious source of terrain information. Institutional DOD production agencies maintained a dogma that MSI was nearly useless as a source of mapping and terrain information. Many service-specific agencies felt the same way. However, several organizations refuted this negative position and prevailed in establishing educational and training opportunities. Their goal was the establishment of MSI as a source of information that could be exploited profitably at the tactical level. Organizations most effective in this pursuit included:

- Army Deputy Chief of Staff for Intelligence - Imagery Branch;
- Army Intelligence and Threat Analysis Center (ITAC);
- Army Space Command (ARSPACE);
- U.S. Army 30th Engineer Battalion;
- Naval Space Command (NAVSPACE) Detachment of U.S. Space Command (USSPACECOM);
- Defense Intelligence Agency ;
- U.S. Air Force 497th Intelligence Group (IG).

DESERT SHIELD/DESERT STORM

DESERT SHIELD/DESERT STORM saw the first wholesale application of MSI, led by the organizations listed above. MSI became quite useful among tactical forces and other agencies that soon provided MSI products. MSI developed into a useful tool and provided map supplements to out-of-date maps as well as a terrain database. Products that were of greatest value included:

- USAF Mission Planning (Mission Support System) using panchromatic SPOT imagery as a backdrop for mission planning and in 3D renderings of the battlefield;
- U.S. Army Image Maps produced by the 30th Engineer Battalion;
- U.S. Army Intelligence templates (B&W I-Maps with daily updates of enemy positions E-Mailed from U.S. Army ITAC to Riyadh);
- U.S. Army 30th Engineer Battalion graphics that displayed a B&W image map at the center of a map-size graphic with actual reconnaissance imagery imbedded around the margin. These showed high resolution views of enemy positions not otherwise visible on the lower resolution I-Maps;
- DIA Scud-busting operations.

Former Yugoslavia

MSI production covering the former Yugoslavian area was a free-for-all as agencies attempted to use the capabilities assembled for DESERT STORM. Every unit produced data for their own users, resulting in a plethora of partially coordinated products and images. Perspective views came into their own as a separate product during this period. Several organizations placed dedicated commercial-off-the-shelf (COTS) and government-off-the-shelf (GOTS) mission planning and rehearsal systems with units alerted for possible deployment to the former Yugoslavia.

A variety of products were produced during this event including Image Maps, terrain analysis graphics and useful graphics of the ground routes for relief supplies bound for civilian enclaves. Briefings by MSI production agencies were used to show senior national and military leadership the extremely hostile terrain U.S. forces would face if deployed to that theater. Participants during this period included ARSPACE, NAVSPACE, Air Force Space Command, the former Defense Mapping Agency

(DMA), U.S. Army Topographic Engineering Center (TEC), U.S. Army ITAC, EROS Data Center and the USAF Mission Support System.

Somalia

During operations in Somalia, a large number of organizations pooled resources to acquire and produce MSI products in a fairly coordinated fashion. Most resulting products were centered around Mogadishu, but the Army produced terrain analysis graphics at the Army Space Command, Topographic Engineering Center and at the deploying Army organization, the 10th Mountain Division. The USMC developed products in support of the forces deploying, as did the Naval Space Command, the U.S. Army ITAC and the USAF.

Haiti

MSI support to Haitian operations was similar to that seen in Somalia, with organizations working together to produce a number of what, by this time, had become standard products. One unique product that emerged from the Haitian experience was produced by the Army Space Command, featuring an MSI product in the center of a full-sized Image Map, with video snapshots of key points along President Aristede's repatriation motorcade route.

PRODUCT AND DATA AVAILABILITY

The National Imagery and Mapping Agency (NIMA) was established 1 October 1996. This agency combined into a single organization, the imagery tasking, exploitation, production and dissemination responsibilities as well as the mapping, charting and geodetic functions of eight separate organizations of the defense and intelligence communities.

NIMA incorporates the former DMA, Central Imagery Office (CIO) and the Defense Dissemination Program Office in their entirety as well as the mission and functions of the CIA's National Photographic Interpretation Center

tographic Interpretation Center (NPIC). Also included in NIMA are the imagery exploitation, dissemination and processing elements of the DIA, National Reconnaissance Office (NRO) and the Defense Airborne Reconnaissance Office (DARO).

Besides this major restructuring for support, a new system is in place for the handling of Production Requirements (PRs) within DOD. This system is called COLISEUM, or the Community On-Line Intelligence System for End-Users and Managers. Eventually, anyone with a PC and having access to the Global Command and Control System (GCCS) will be able to enter PRs via this method.

Although NIMA and COLISEUM represent a major change in terms of support to DOD, the process in the Air Force for acquiring MSI is still through intelligence channels. As a result, the Collection Manager remains the best starting point for operational and intelligence driven MSI requirements at the unit level.

The following organizations provide an informal union of MSI related talent especially supportive on short notice and during periods of crisis and contingencies:

- ARSPACE;
- NAVSPACE;
- Air Force Space;
- U.S. Army TEC;
- USAF 480th IG (replaced the 497th IG as MSI POC);
- USSPACECOM MIMES (Joint requirements only).

MSI PROCESSING REQUIREMENTS

The following information is provided as a means for students to understand common processing requirements for MSI products.

Softcopy systems:

- CPU: PCs will support elementary processing, although standards for

production systems call for UNIX work stations

- I/O Devices: CD-Player, 8mm & 4mm tape reader/writer
- Storage: Large Disk Drive (typically no smaller than five GB, although production systems may have greater than 25GB of storage)
- Graphic display screen: 8-bit color supports elementary processing; 24-bit color is required for analysis and production activities

Hardcopy systems:

- CPU, I/O, Storage and Display: same capabilities as soft-copy systems
- Hardcopy Output: High resolution color printers of the size required to support the application

Rectification requirements:

- A means of establishing ground control
- A means of associating ground control with features on the image (software)
- Software to “warp” or rectify the image to a specified coordinate system

Orthorectification:

- A means of establishing extremely accurate ground control
- A means of associating ground control with features on the image
- Software to warp image to a coordinate system and elevation

Digital Elevation Data Extraction:

- Orthorectification capability
- Software to extract the digital elevation matrix

Perspective View Generation:

- Imagery of the area of interest
- An elevation matrix (file) of the area of interest

- Software to process imagery and elevation data into a softcopy or hardcopy graphic

RESOLUTION REVOLUTION

With the successful launch of Space Imaging's IKONOS 2 in 1999, the spatial resolution available with commercial imagery has improved significantly. IKONOS 2 offers one meter panchromatic and four meter multispectral imagery, using bands similar to LANDSAT. By 2003, it is expected that there will be somewhere in the range of 13 satellites from five different nations on orbit with one meter or better panchromatic. Some of these satellites will also have MSI and even hyperspectral imagery (HSI) with eight meter or better resolution. HSI will provide capabilities similar to MSI, but with greater refinement. Instead of collecting reflectivity in seven relatively wide bands as we do with Landsat, HSI sensors will collect against hundreds of narrower bands. It is expected that this will greatly improve the ability to discriminate between various materials as previously explained in discussing Figure 12-8.

MSI LEXICON

- **Digital Image** - an image that has been placed in a digital file with brightness values of picture elements (pixels) representing brightness of specific positions within the original scene. The original scene may be the Earth as digitized by sensors in space or it may be a picture scanned by a desktop or other variety of scanner
- **Hyperspectral Imagery** – similar to MSI but with data collected in hundreds of spectral bands. The increased number of sensor bands provides higher spectral resolution and more opportunities to detect subtle spectral differences in signatures that are too narrow to be differentiated on MSI.
- **Multispectral Imagery** - imagery collected by a single sensor in multiple regions (bands) of the electromagnetic spectrum.
- **Panchromatic Imagery** - black and white imagery that spans an area of the electromagnetic spectrum, typically the visual region.
- **Pixel** - Picture element, the smallest element of a digital image.
- **Radiometric resolution** - the ability of a sensor to detect levels of reflectance.
- **Resolution** - a unit of granularity.
- **Spectral resolution** - the ability of a sensor to detect information in discrete regions of the EM spectrum.
- **Spatial resolution** - the smallest sized feature that can be distinguished from surrounding features usually stated as a measure of distance on the ground and, in a digital image, directly associated with pixel size.
- **Temporal resolution** - the span of time between collection of successive images.

OPERATIONAL EARTH OBSERVATION SATELLITES

Table 12-1 is provided as a reference for operational Earth Observation Satellites.

Table 12-1. Operational Earth Observation Satellites*

SYSTEM	SENSOR	LAUNCH DATE	ORBIT (km/degrees)	SPATIAL RESOLUTION (in meters)	TEMPORAL RESOLUTION (in days)	SWATH (in km)
Canada						
Radarsat	SAR	4 Nov 95	792 / 98.6	8 - 100	24	50 - 500
ESA						
ERS-1	SAR	17 Jul 91	780 / 98.5	26 / 102	35	100
ERS-2	SAR	21 Apr 95	780 / 98.5	26	3 - 35	99
France						
SPOT 1	Pan, MSI	22 Feb 86	825 / 98.7	10 / 20	2.5 - 26	117
SPOT 2	Pan, MSI	22 Jan 90	820 / 98.7	10 / 20	2.5 - 26	117
SPOT 4	Pan, MSI	24 Mar 98	820 / 98.7	10 / 20	2.5 - 26	
India						
IRS-1B	Pan, MSI	29 Aug 91	900 / 99.3	36.25 / 72.5	22	148
IRS-1C	Pan, MSI	28 Dec 95	817 / 98.69	5.8 / 23.5 / 70.5	24	142
IRS-1D	Pan, MSI	28 Sep 97	300 x 823 / 98.6	5.8 / 23.5 / 70.5	24	142
IRS-P2	MSI	15 Oct 94	817 / 98.6	36.25	22	142
U.S.						
LANDSAT 5	MSI	1 Mar 84	705 / 98.2	30	16	185
LANDSAT 7	Pan, MSI	15 Apr 99	705 / 98.2	15 / 30	16	185

*Basic information taken from Jane's Space Directory, 1995-96 and updated with *Air Force Magazine* (April 1997) and various Internet references.

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Commercial Satellite Imagery Providers Websites:

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Orbital Imaging Corporation	http://www.orbimage.com/
Space Imaging, Inc.	http://www.spaceimaging.com/
SPOT Image Corp.	http://www.spot.com

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