Highlight Article

The Era of Commercial Earth Observation Satellites

Lawrence W. Fritz

In the spring of 1996, the first of several commercially owned and operated, very high resolution, digital Earth observing satellite systems will be launched into polar orbit. This event will initiate a new era of commercial Earth observation satellites which may revolutionize the structure and direction of the entire photogrammetric/remote sensing community. Currently three companies in the U.S.—EarthWatch, Space Imaging, and Orbital Sciences—have high-resolution imaging satellites under development and are establishing international strategic partnerships for reception, processing, and distribution.

In aggregate, these and other proposed electro-optical systems will produce panchromatic images with spatial resolutions of 1-3 m and from 4-15 m in the multispectral bands. The systems are distinguished by their flexible pointing ability, high geometric fidelity, and very rapid image-collection to customer delivery. A prognostication of the impact on the photogrammetric/remote sensing community is offered based on market projections; in addition some summary capabilities, technical characteristics, and related issues are discussed.

A Revolution

We are about to witness a revolution which may forever change the direction of our profession! After 35 years of government domination of Earth observation satellite systems, the private sector is taking the initiative.

Ever since the first artificial satellite was placed in Earth orbit there have been three especially promising areas for space commercialization: communications, remote sensing, and materials processing. The commercial satellite communications industry was spawned from government operations in the early 1960s and has prospered ever since. Materials processing in space is still in experimental stages and has yet to mature in to a viable commercial activity. Satellite remote sensing is just crossing the threshold into maturity as a commercial space activity. A review of existing Earth observation satellites will not be given; suffice it to say that all existing Earth observing systems have been designed and developed with government funding for government programs, including the quasi-commercial systems such as Landsat, SPOT, and Resurs-F.

Traditionally, Earth observation satellites have been categorized into three types: reconnaissance, meteorological, and Earth resources. A fourth type, commercial, soon will be launched. During the next ten years, there are plans for the launch of 99 Earth observation satellites of all types, plus two to three Cosmos satellites per year. Fifty-seven of these are scheduled for launch before the end of 1999; this number is expected to increase.

Why, after so many years, are Earth observation satellite systems suddenly becoming a competitive arena for commercial opportunities? There are many reasons, the foremost of which is the end of the Cold War. With the downsizing of major defense programs there is an emergence of "dual-use" technology, or the use of previously-proven defense technology for civil applications. The sale of imagery produced by formerly Russian reconnaissance systems is a prime example. Another reason for commercialization is the unfortunate failure to orbit Landsat 6, and the end of Landsat 4's useful operability. Landsat and SPOT have received U.S. and French government support but have not achieved the commercial success for which many had hoped. Market projections by commercial firms now link the promise of geo-spatial information systems to the markedly reduced costs

Why are Earth observation satellites becoming a competitive arena for commercial opportunities?

of developing and launching satellites, resulting in very attractive market opportunities. Advancements in digital technology allow satellite systems, which easily could have cost $1 billion dollars ten years ago, to be built now for under $100 million. The U.S. Department of Commerce responded positively to industry requests to permit high-resolution imagery to be collected and distributed internationally on a non-discriminatory, commercial basis. As a result, Earth observation satellites now being developed to serve an expected $2 billion commercial imaging market will offer up to 1 m spatial resolutions by the year 2000. Currently the satellite and aircraft imaging market is estimated to be about $700 million.

With the progression of "The Information Age," it seems that society

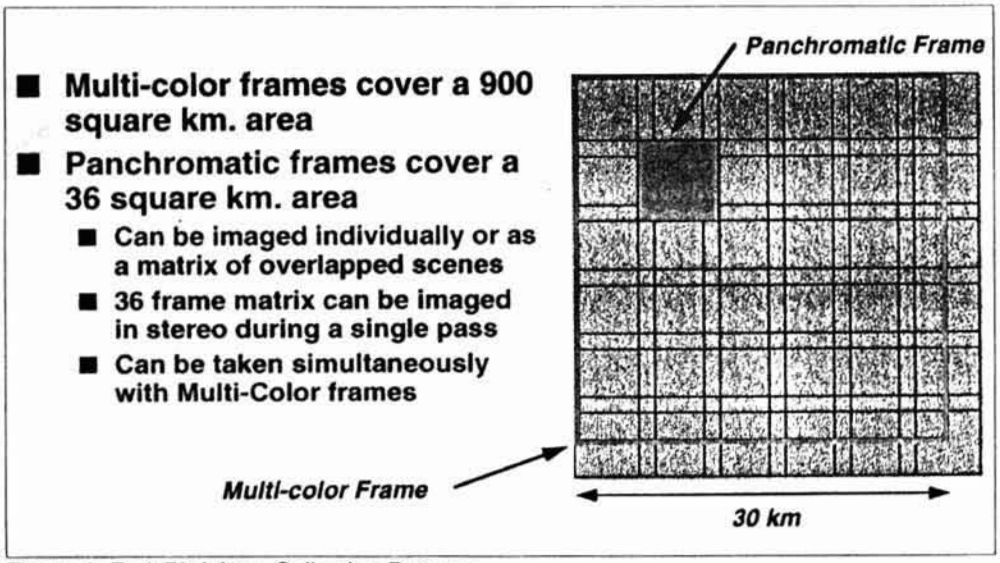


Figure 1. EarlyBird Area Collection Patterns.

craves information. Although information for traditional public products such as maps would often take seven years to produce from the planning stage, today this delay is unacceptable. In addition, the GIS and "precision farming" markets are demonstrating the high value of temporal information for updates and forecasts: the sooner information is produced the more often and quicker consumers demand it. This insatiable need for information will extend to the imaging market and commercial imagery can satisfy the demand, especially for geo-spatial information. It is estimated that as much as 80% of the information used in decision making processes has a geo-based context.

Given this rationale and the potential for viable commercial opportunities, several corporations have begun their quest to design, develop, field, and operate high-resolution Earth observation satellites, and to form international corporate alliances and partnerships to maintain the system infrastructures necessary to sustain full-service imaging production capabilities.

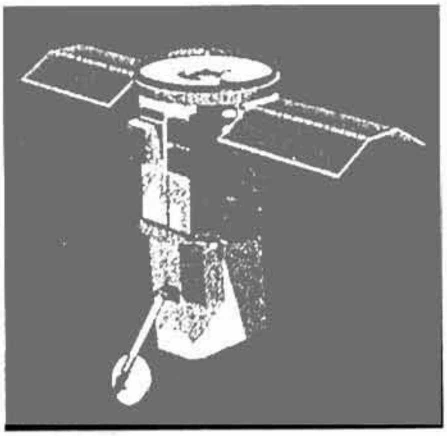
EarthWatch Inc.

The merger of the commercial remote sensing activities of the former WorldView Imaging Corporation and the Ball Corporation brought together two distinctly different technical approaches, and created EarthWatch, Inc. EarthWatch provides a formidable constellation of imaging systems to address the breadth of the applications market. Headquartered in Longmont, Col., EarthWatch is managed by Dr. Richard Herring, Chief Executive Officer, a Senior Vice President from Ball Corporation; Douglas B. Gerull, President and Chief Operating Officer, former Executive Vice President and head of the Mapping Sciences Division of Intergraph Corporation; and Dr. Walter Scott, Chief Technical Officer and former SDI Program Manager at the Lawrence Livermore National Laboratories.

The EarthWatch imaging systems, "EarlyBird" and "QuickBird," are designed to fulfill the imagery needs of the international GIS/mapping community, and civil and military reconnaissance programs. With a combination of 1-, 3-, 4-, and 15-meter resolutions available from two types of satellites orbiting in tandem, EarthWatch offers the user a wide choice of metric and spectral options. EarthWatch plans to launch the 3- and 15-meter resolution EarlyBird in April 1996 followed by a July 1997 launch of the 1- and 4-meter resolution QuickBird. Subsequent satellites will be launched based on market demand, although two of each satellite are under construction. EarlyBird's two-dimensional CCD staring array cameras are unique and both its panchromatic (pan) and multispectral (MS) digital images will have the attributes of traditional film image frame cameras. Its design is intended to offer rigid photogrammetric geometry for the high metric accuracies needed by the GIS and mapping communities. EarlyBird's MS frames cover an area of 30 by 30 km over which it can image simultaneously 6 by 6 km pan scenes (Fig. 1). The entire MS frame can be covered in stereo by 36 pan scenes. Using photoidentified control, EarlyBird is capable of providing an RMS accuracy of 6 m horizontally and 4 m vertically for GIS/mapping projects. The range of the three MS wavebands of EarlyBird and the four MS wavebands of QuickBird are almost identical to SPOT bands 1-3 and Landsat bands 1-4 respectively. Figure 2 illustrates the QuickBird configuration. The MS and pan imagers of QuickBird share a common aperture.

Unlike its competitors EarthWatch states that it will "retain ownership and possession of all data collected by its satellites. It will maintain a complete Digital Globe (representing images and elevation data for every point on the Earth), and will make

. . . As much as 80% of the information used in decision making has a geo-based context.



- Pushbroom imaging systems
- 1-meter GSD panchromatic sensor
  - 450- to 900 nm
- 4-meter multi-color sensor
  - Blue 450 to 520 nm
  - Green 530 to 590 nm
  - Red 630 to 690 nm
  - Near IR 770 to 900 nm
- Spacecraft articulates for along- and cross-track pointing ±30 degrees
  - In-track stereo, max b/h = 1
  - 1.5 to 2.5 day revisit time (polar orbit)
- Large on board image data storage >100 image sets at 36km x 36km
- Lightweight spacecraft and payload, existing designs. Five year fuel

Figure 2. EarthWatch's QuickBird (1m) configuration.

this archived imagery available at highly competitive prices for those customers who place priority on easy access and quick response." EarthWatch ground stations will transmit raw imagery to Longmont, Col. headquarters where geometric and radiometric calibrations, processing, and archiving will be performed. The corrected imagery can then be transmitted to a customer or EarthWatch distributor. The entire process from satellite to consumer can be accomplished in about 15 minutes. The underlying philosophy is to keep the data in digital form to ensure image quality and utility, as well as speed of delivery.

Orbital Sciences Corp. ORBIMAGE

The Orbital Sciences Corporation (OSC) is the U.S. leader in lightsat launches, distinguished by its Pegasus launch vehicle. ORBIMAGE is an OSC company specializing in providing global imaging information and developing new remote sensing, Earth observation, and environmental products and services. "SeaStar," the first of its imaging systems, is scheduled to be launched in 1995 to measure daily levels of phytoplankton chlorophyll in the oceans. OSC and ORBIMAGE headquarters are located in Dulles, Vir.; ORBIMAGE is managed by Gilbert D. Rye, President, and Armand D. Mancini, Vice President.

The OrbView-1 imaging system is being designed to supply high-quality, low-cost imagery products and services for commercial, civil, and military markets. The initial satellite, (Fig. 3), will include a 1- and 2-meter resolution pan sensor and an 8-meter resolution MS sensor which will share a common aperture. It is scheduled for a Pegasus launch in the fall of 1997 and has a design/expected life of three to five years. OrbView-1 features an electro-optical camera that can image scenes 45° off axis in all directions. Such flexibility provides an average revisit time of 1.8 days at the equator, 1.5 days at ±30° latitudes, and 0.9 day at latitudes of ±60°. The typical scene size is 8 by 8 km, but its collection capabilities are highly flexible, (Fig. 4). Combining photo-identifiable control with OrbView-1's high-resolution stereo imager enables routine cost-effective generation of geodetically correct 1:24,000-scale maps with 6-meter contours.

ORBIMAGE is establishing a network of international distributors located near existing ground receiving and processing stations. Each of the distributors will be licensed by ORBIMAGE to receive imagery in real-time and sell OrbView imagery to customers in their nation or geographic region of the world. ORBIMAGE will support these distribution centers with the capability to produce a variety of standard products such as orthorectified image maps, seamless mosaics, contour maps, DTMs, stereopairs, image enhancements, perspective scenes, etc. ORBIMAGE will archive and disseminate data to its distributors through ORBNET which is scheduled to come online in early 1996 to supply SeaStar data, aerial photos, etc.

Space Imaging, Inc.

On 15 May 1995 Space Imaging, Inc. opened its headquarters in Thornton, Col. having relocated from Sunnyvale, Cal. Formed initially by Lockheed Missiles and Space Co., Space Imaging is now an independent corporation of which Lockheed Martin, E-Systems, and Mitsubishi are

Figure 3. OrbView-1 is based on the flight-proven MicroLab spacecraft bus.

As imagery demands increase, companies plan to launch additional satellites . . .

minority partners. Space Imaging, Inc. is directed by John Neer, President and Chief Executive Officer.

The Space Imaging system is designed to cover large-area swaths of high-resolution imagery from its 680 km orbit. The system has an expansive field of regard, (Fig. 5) and uses GPS in conjunction with three digital star trackers to maintain precise camera station position and attitude. Thus it can provide absolute positioning without ground control in the 12-15-meter range. With the addition of ground control points (GCPs) and terrain elevation data, the system is projected to support high-precision orthophotos that will meet National Map Accuracy Standards for 1:2,400-scale mapping.

Uplinks to the satellite contain user-requested latitude/longitude bounds, desired bandwidths, and tasking (imaging) priorities. The fore and aft collection of overlapping swaths provides optimal base-height ratios for a stereo scene on the same orbital pass, plus opportunities for additional imaging during the same time frame. System users receive confirmation of tasking, and subsequently receive the imagery and its metadata for processing.

Space Imaging is establishing a network of regional affiliates which will have site licenses for uplinking, tasking, and direct sales; regional and portable ground stations will task and control image acquisition. Figure 6 illustrates an overview of Space Imaging's operations. Corresponding regional remote sensing facilities will maintain local archives and process the imagery for customers into the following seven standard products:

- Radiometrically Corrected—distortions removed for "quick-look" monitoring of specific events,
- Standard Geometrically Corrected—rectified without GCPs (to a selection of map projections) for reconnaissance and monitoring,
- Precision Geometrically Corrected—rectified with GCPs for high precision orthophotos (up to 2 m horizontal accuracy),
- Orthorectified—precision geometrically corrected including terrain elevation data to support up to 1:2,400-scale orthophotos,
- DTM—elevations generated from stereopairs,
- Multispectral—pan-sharpened MS (fused pan and MS) or band ratio images (selective fusing of MS bands),
- Image Mosaics—single continuous image scene created from contrast/brightness balancing of multiple overlapping images.

Technical Information Summaries

All of the proposed U.S. systems are in the smallsat, lightsat categories and are planned for polar sun synchronous orbits to provide maximum global terrain coverage. As imagery demands increase, each of the companies mentioned plans to launch additional satellites to provide constellation coverage increasing imaging opportunities for optimal sun angles, repetitive coverage, stereo coverage, and timely monitoring of events. Generally, the orbits are circular, low-Earth orbits (LEOs). Orbit altitudes have been influenced by market considerations, such as optimizing repetitive coverage (revisit) intervals, or for ground station agreements with regional and national affiliate distribution centers. Except for the two-dimensional pixel staring arrays of the EarlyBird, the sensors are all of the pushbroom type and provide 8-bit or 11-bit pixel data streams. Their MS capabilities are similar and include the red, green, blue bands of the visible and the near infrared bands which generally replicate the bands of Landsat and SPOT. Each of the systems will rely on a store-and-forward operation with capabilities for some quantity of on-board storage to allow for ground station access and perhaps some preprocessing activities, such as data compression. To achieve precision-pointing to customer areas of interest, the systems all use on-orbit GPS positioning. One of the remarkable characteristics of these systems is their ability to point to multiple areas of interest within very short time intervals enabling them to, for example, provide opportunities to optimize stereo base-height ratios or to acquire off-track stereo imaging if requested.

In addition, other companies have received Department of Commerce licenses for commercial remote sensing. In June 1995, GDE Systems, Inc. was licensed for a panchromatic 0.85-meter resolution satellite sensor system. Its technical characteristics and marketing approach is under development and not ready to be announced. Another commercial remote sensing activity is the Resource 21 consortium. Resource 21 is developing a constellation of six satellites in multiple orbits to provide two to three daily revisits to any global site with its 10-meter resolution MS sensors (6 bands: 4 visible, 1 IR, 1 SWIR). GDE and Resource 21 are forming an agreement to collaborate in their respective markets.

Each of the companies has a different approach for providing imagery and imagery products. The main points are that the high resolution companies offer imagery of spatial resolution from one to ten magnitudes higher than is commercially available from current space systems *and*

Continued on page 44

Highlight Article

Table 1. New Commercial Earth Observation Satellites - General Information

Corporation	**EarthWatch**				**Orbital Sciences**		**Space Imaging**	
System	*Early Bird*		*QuickBird*		*OrbView-1*			
Mode	Pan	MS	Pan	MS	Pan	MS	Pan	MS
Pixels	8-bit	3 8-bit arrays	11-bit	4 11-bit arrays	8-bit	8-bit	11-bit	11-bit
Data Size	4MB	12MB	3.5Gb	14.2Gb	128Mb	128Mb	*TBA*	*TBA*
On-Orbit Date	April 1996		July 1997		Dec 1997		Dec 1997	
Imager Type	Staring Array		Pushbroom		Pushbroom		Pushbroom	
Payload (kg)	< 100		~ 150		150		225-275	
Altitude (km)	470		470		460		680	
Inclination	97.3, sun sync.		Polar/52 TBA, sun sync.		97.25, sun sync.		98.10, sun sync.	
Repear Cycle (max)	20 days		20 days		16 days		14 days	
Revisits Cycle (max)	1.5-2.5 days		1.5-2.5 days		< 3 days		1-3 days	
Period (revisits/day)	15.3		15.3		15.5		14.6	
Partners	Ball Corp. Hitachi Ltd. NUOVA Telespazio s.p.a. CTA, Inc. Datron Systems, Inc.				Orbital Sciences EIRAD Co. Ltd. PR Applied Sciences Fairchild Event Systems MDA Ltd.		Lockheed E-Systems Mitsubishi	

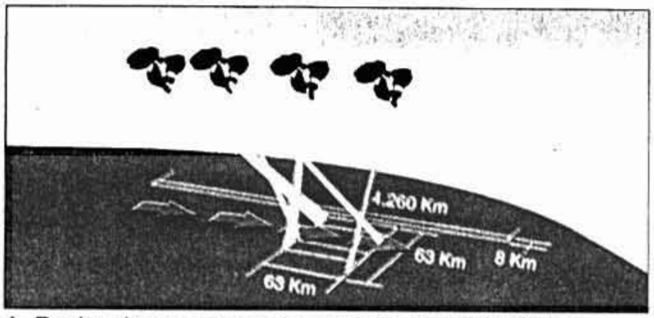
Table 2. Communications/Processing Information

Corporation	**EarthWatch**		**Orbital Sciences**	**Space Imaging**
System	*EarlyBird*	*QuickBird*	*OrbView-1*	
Scenes (max)	500/orbit	100/orbit	535/day	process 600/day
On-Board recording	Yes, 500 scenes	Yes, 100 scenes	Yes, 250 scenes,32 Gb	Yes, 120 Gb
Delivery time from Acquisition to User	15 min.-48 hr.	15 min.-48 hr.	15 min.-24 hr.	24 hr.-48 hr.
Ground Station Sites	EarthWatch-owned—Cal., Ala., Europe		Regional Affiliates	Denver, Ala., Japan, Regional Affiliates

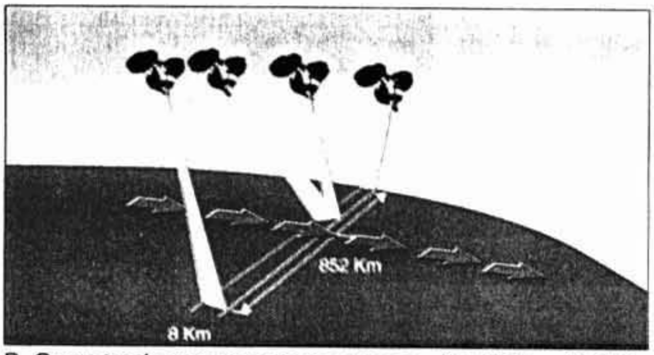
Table 3. Sensor Information

Corporation	**EarthWatch**				**Orbital Sciences**		**Space Imaging**	
System	*Early Bird*		*QuickBird*		*OrbView-1*			
Mode	Pan	MS	Pan	MS	Pan	MS	Pan	MS
Resolution (nadir GSD)	3 m	15 m	1 m, 2 m	4 m	1 m, 2 m	8 m	1 m	4 m
Spectral Bandwidths (μm)	.45-.80	.50-.59 .61-.68 .79-.89	.45-.90	.45-.52 .53-.59 .63-.69 .77-.90	.45-.90	.45-.52 .52-.60 .63-.69 .76-.90	.45-.90	.45-.52 .52-.60 .63-.69 .76-.90
Swath Width (km)	6x6	30x30	36	36	8	8	11	11
Scene Size (at nadir)	36 km²	900 km²	36x36 km	36x36 km	8x8 km	8x8 km	60x60 km	60x60 km
Accuracy,	Horiz	Vert	Horiz	Vert	Horiz	Vert	Horiz	Vert
with GCPs	6 m	4 m	2 m	3 m	2 m	3 m	2 m	3 m
w/out GCPs	---	---	---	---	12 m	8 m	12 m	8 m
Stereo	In track		In track		In track		In and cross track	
Field of View	*TBA*		*TBA*		1		.93	
Pointing, in track	30		30		45		45	
cross track	30		30		45		45	
Sensor Position	GPS		GPS		GPS		GPS	
Sensor Attitude	No		Star Trackers		Star Trackers		3 Star Trackers	

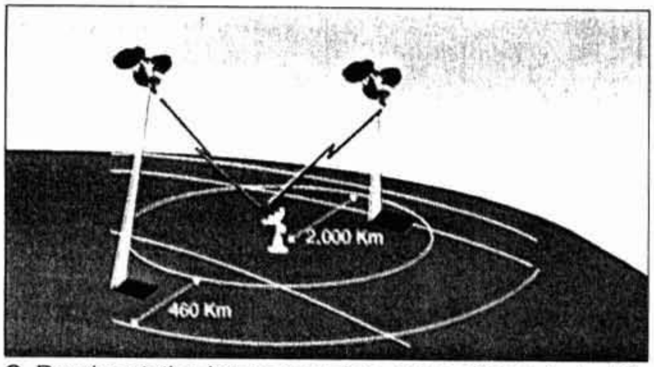
Figure 4. OrbView sensor system acquisition modes.



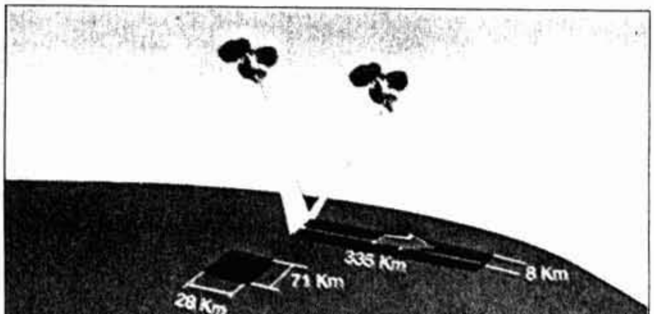
A. Regional area coverage per pass - four 63 x 63 km (15,876 km²) areas or one 8 x 4,260 km (34,080 km²) mono-scopic swath can be acquired in a single pass.



B. Cross track area coverage per pass - 8 x 852 km (6,816 km²) cross track coverage is possible.



C. Receive station images per day - up to 107 equivalent 8 x 8 km (6,848 km²) scenes can be received each day per station.



D. Stereo coverage per pass - 8 x 335 km (8,040 km2) stereo strip or four 28 x 71 km (7,952 km2) area can be acquired in a single pass.

Continued from page 4

which is metrically, spectrally, and temporally precise, *and* which nominally can be delivered from near-real-time to 48 hours from image acquisition! Summaries of the technical and operational aspects of these commercial systems are listed in tables 1, 2, and 3.

As with any new system, it should be expected that some of these characteristics will change during development and before launch of these systems.

Market Maturity Issues

International acceptance of the concept for high-resolution space imaging systems to commercially deliver image data on a daily basis—until recently the privileged domain of governmental organizations—is a primary issue soon to be tested. When these commercial systems come online, the need for an international consortium may arise (perhaps an INTEOSAT along the lines of INTELSAT).

From the commercial market viewpoint it is clear that the technology has matured and the projected demand for GIS, mapping, natural resource, environmental, news, Earth monitoring information, etc. warrants the risk. Market projections for this industry's products consistently estimate growth to be $8 billion by the early years of the new millenium. The bulk of initial sales will likely be to governments, since that is where most world mapping and reconnaissance programs are funded. However, the commercial GIS market is expected to flourish rapidly because of the cost effective, synoptic, accurate, and repetitive coverage these systems can provide. It is anticipated that well over 50% of the imaging provided by the aerial survey market will be replaced by this high-resolution satellite imagery. Even with the high capitalization costs of satellite systems, their advantages of imaging timeliness, rapid delivery, digital form, simultaneous pan and MS coverage, superior coverage per processing unit, repeat times, radiometric dynamic range and stereometric fidelity make them very cost-competitive with aerial images. In fact, for square unit of coverage, aerial images are projected to be more than twice as expensive to acquire.

Many have speculated whether the marketplace for imagery is sufficient to sustain multiple commercial high-resolution space systems—especially since the infrastructure for modeling, enhancing, and extracting spatial information from digital imaging systems is currently quite limited in most regions of the world. However, years of experience from information processing (mostly thematic) of digital remote sensing data using Landsat, SPOT, AVHRR, etc. will assist the transition. There is a rapidly growing need for temporal change data to provide information for global, regional, national, and urban infrastructure activities. In the rush and glamour to exploit outer space, governments gave

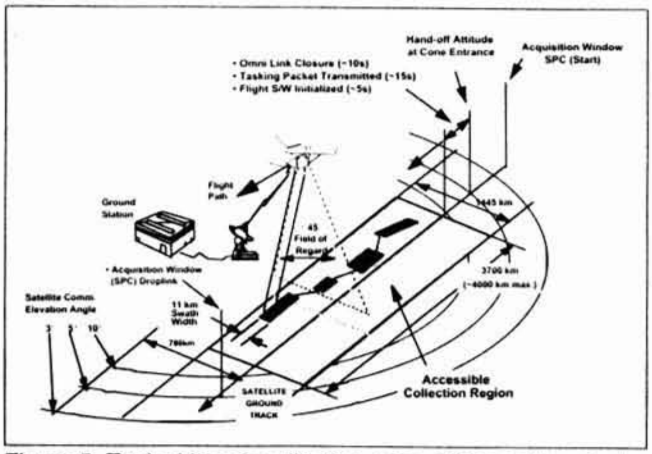
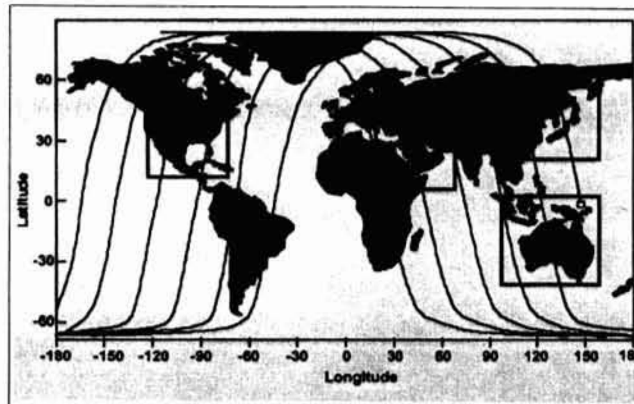


Figure 5. Typical image collection pass of Space Imaging's system.



Regional Architecture
- U.S. ground station with 2-3 terminals
- Central imagery processing & distribution
- Regional ground stations —"user friendly" tasking and processing
- Transportable ground stations
- One constellation (1 as spare)

Operations Concept
- < 1-m pan, <4-m MS real-time imagery
- Small-to-medium area collection
- Wide area access
- Limited store-and-forward collection
- 680 km, sun sync. orbit
- 1.4 passes/day (avg./ground station)
- 3 day revisit at 1m, 40°; 2 days at 1.5m

Figure 6. Overview of Space Imaging's operations.

priority to fund imagery collection systems and allocated very limited resources for development of efficient imagery exploitation systems. As a result, many remote sensing images were archived and never used. These new corporate entities recognize such infrastructure needs. In forming corporate partnerships and distribution alliances, each of the U.S. companies uses different strategies, providing many consumer alternatives for value-added images (georegistration, orthorectification, feature enhancement, radiometric intensification) and value-added products (DTMs, orthophotos, image mosaics, fused MS and pan scenes). This total service capability environment will strongly influence the entire GIS/mapping community to coalesce many of its traditionally fragmented, small (colloquially known as Mom and Pop outfits) corporate businesses into large corporate entities or conglomerates. This should not be considered a negative sign, but rather one of technological, industrial, and scientific maturation. The market will increase as consumers become more sophisticated and less concerned with the technical complexities of image processing, traditionally a necessity. Quite conceivably, growth of these companies will lead to significant commercialization of many government mapping programs.

Acknowledgements

It is with great appreciation that I thank Dr. Richard Herring and Douglas Gerull of EarthWatch, Gilbert Rye and Armand Mancini of OSC, and John Neer and Bill Folchi of Space Imaging for sharing information and graphics on their systems.

About the Author

Dr. Lawrence Fritz is Senior Staff Scientist with Lockheed Martin Corporation in Rockville, Maryland. He is currently serving as ISPRS Secretary General.

Would you like to see your company's imagery on the cover of *Photogrammetric Engineering and Remote Sensing*?

Contact Joann Treadwell for details,
301-493-0290, fax 301-493-0208, email jtread@asprs.org