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Recent Developments for Optical Earth Observation in the United States

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ABSTRACT

Three USA companies are developing high resolution earth observing satellite systems for launch before the end of 1997. These are privately financed commercial endeavors. In aggregate, these electro-optical systems will produce images with spatial resolutions of one to three meters in the panchromatic band and from four to fifteen meters in the multispectral bands. The systems are also highlighted by their flexible pointing ability, high geometric fidelity and very rapid image-collection to customer-delivery. The technical characteristics, corporate descriptions, surrounding issues and summary capabilities are discussed.

1. INTRODUCTION

In the Spring of 1996 the first of many new high resolution commercial earth observing satellites will be launched into sun synchronous orbit. It is aptly named "EarlyBird". Its launch marks the advent of a new era for the photogrammetric and remote sensing sciences! The large volumes of high resolution data which will be extracted from this metric digital imagery positions these disciplines at the forefront of the spatial information sciences, and it portends great opportunities and challenges for our profession.

Commercialization of earth observation systems in space is becoming a reality. For several decades, discussions about the most promising markets for applications from space technology have always included communications, remote sensing and microgravity as the leading candidates. Space systems for communications have clearly been the leader in profitable commercial operations and their continual advancements have helped pave the way for profitable commercial remote sensing systems. Initial indications which forecast the viability of commercial remote sensing were recognized through the successes of meteorological and military reconnaissance systems. But these are inherent governmental functions and not viable activities for privatization. In 1972 the Landsat series were initiated and demonstrated their capabilities for providing repetitive earth resource information. Today the Landsat, SPOT, IRS, Resurs and other nationally developed earth observing systems are operational and are supplying governments, science communities and a limited, but growing, commercial remote sensing market with medium resolution imagery. However, the proliferation of earth observation systems for civil mapping applications has been a government dominated industry. This has been perpetuated for a variety of reasons, the foremost being that the high resolutions required for mapping have been considered as an infringement on the vested security and political interests of nations. Private sector management and control has, in the most part, been over the ground processing, interpretation and distribution of imagery and not over sensors, platforms and imaging capabilities.

This scenario is now changing. A series of influencing events have occurred in the early 1990's that are creating the opportunity to usher in the "commercial era of high resolution (digital) imagery". These events were led by the cessation of the cold war which permitted the lifting of imagery veils and international acceptance of "Open Skies from Space" for peaceful uses. Some of the other influencing events/factors include: (a) The loss of Landsat 6 in its unsuccessful launch, coupled with the failure of Landsat 4 operational capabilities, and the inability of a NASA/DoD Joint Program Office to negotiate the technical and financial aspects of Landsat 7; (b) Major advancements in technology which significantly reduce the cost and weight of imaging payloads, such as efficient data compression routines and advanced communications capacities, magnitude improvements in computer storage and processing technologies, etc; (c) Emergence of a burgeoning GIS industry which is becoming

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increasingly reliant on obtaining current data which only the imaging industry can best supply; (d) The expansion of the global market for remote sensing imagery with increased demands for higher resolutions, timely acquisition and delivery of image products.
As a result many nations have begun, or have indicated their intent, to develop high resolution space imaging systems. A general, non-exhaustive list of these nations and their proposed systems is given in figure 1.

Country	Satellite	Spatial Resolution
France	Helios NG	1 m
	SPOT-4	5 m
Germany	MOMS-3	4 m
Israel	Offeq-3	2-3 m
Russia	KFA-3000	.75-1.5 m
South Africa	Greensat	2.5 m
Spain	Minisat	3-5 m

Figure 1: Government Proposed High Resolution Satellites.

Other nations which may join this list include China, India, Japan, South Korea and Taiwan.

2. NEW COMMERCIAL HIGH-RESOLUTION EARTH OBSERVATION SYSTEMS

Recognizing that there is considerable competition for the global market in remote sensing and recognizing their vested interests in maintaining technological leadership in the development of imaging systems, several leaders of the American aerospace industry petitioned the US government to ease restrictions which regulate private ownership and operation of earth observation systems. The US Land Remote Sensing Commercialization Act of 1984 which addressed Landsat policy was repealed on October 28, 1992 by enactment of US Public Law 102-555 titled the "Land Remote Sensing Policy Act of 1992". This law authorizes the Secretary of the US Department of Commerce to license US companies to operate private remote sensing space systems. A license permits unrestricted availability of imagery, limited only by US government national security and international obligations. In general, this has been interpreted as permitting images up to one meter resolution. With the removal of these US government barriers for commercial imaging satellites, several US companies activated their plans to develop high resolution digital remote sensing systems which will be totally financed with private capital. Thus, a new competitive commercial marketplace has arisen.
In January 1993 the WorldView Imaging Corporation of Livermore, California was granted the first commercial license to manufacture and operate three meter resolution remote sensing satellites. Subsequently one meter resolution licenses were granted: to Lockheed Missiles & Space Co. of Sunnyvale, California in April 1994; to Eyeglass International, a joint venture of Orbital Sciences Corporation, Litton-Itek Corp. and GDE Systems in May 1994; and to the Ball Corporation, Aerospace & Communications Group of Broomfield, Colorado in September 1994.
These four companies, as well as other international competitors, have been evaluating the market, forming financial and strategic partnerships, refining their strategic plans and refining their technical designs. That is, for example, in January 1995, the commercial remote sensing efforts of the Ball Corporation and WorldView Imaging Corporation were merged; in late November 1994 Howteq, a division of the South African Denel Group, indefinitely suspended its development of its Greensat Program; and in May 1995 Orbital Sciences Corporation restructured its consortium, redesigned its technical specifications and changed the system name from "Eyeglass" to "OrbView".
A review of the status of each of the three US companies and a brief summary of the unique aspects of their technical and strategic approach to address the commercial market is provided in the following

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four sections. For ready reference, figures 2 - 5 provide a status summary of the current (mid-May 1995) technical characteristics of their systems. As with all developments, especially in a highly competitive market such as this, it should be expected that several technical characteristics may change before the on-orbit dates. However, all of the systems' components are based on proven technology which should modulate risks. Each of these ventures requires hundreds of millions of dollars of capital investment and the formation of multiple international alliances. Any changes will be driven by business decisions to reduce risk because, unlike all previous space imaging systems, these systems are totally financed without government funding!

Corporation "System"	**EarthWatch** "EarlyBird"		**EarthWatch** "QuickBird"		**Orbital Sciences** "OrbView-1"		**Space Imaging**	
Mode	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**
Partners	Ball Corporation CTA, Inc. Telecom Italia Hitachi Ltd.				Orbital Sciences		Lockheed E-Systems Mitsubishi	
On-Orbit date	Apr 1996		July 1997		Fall 1997		Dec 1997	
Imager Type	Staring Array		Pushbroom		Pushbroom		Pushbroom	
Pixels	8 bit	8 bitx3	11 bit	11 bit	8 bit	8 bit	11 bit	11 bit
Data Size	4MB	12MB	3.5Gb	14Gb	128Mb	128Mb	?	?
Payload	< 100 kg		– 150 kg		150 kg		– 225-275 kg	

Figure 2: General Information.

Altitude (km)	470	470	470	680
Inclination (deg)	97.3E, sun sync.	Polar, sun sync.	Polar, sun sync.	– 99E, sun sync.
Repeat Cycle	20 day (max)	20 day (max)	16 day (max)	14 day (max)
Revisits Cycle	1.5-2.5 da (max)	1.5-2.5 day(max)	< 2 day (max)	1-3 day (max)
Period (rev/da)	15.3	15.3	15.3	14.6

Figure 3: Orbit Information.

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Corporation "System"	**EarthWatch** "EarlyBird"		**EarthWatch** "QuickBird"		**Orbital Sciences** "OrbView-1"		**Space Imaging**	
Mode	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**	**Pan**	**MS**
Resolution (Nadir GSD)	3m	15m	1m	4m	1m & 2m	8m	1m	4m
Spectral Bandwidths (µm)	.45-.80	.50-.59 .61-.68 .79-.89	.45-.90	.45-.52 .53-.59 .63-.69 .70-.90	.50-.90	.45-.52 .52-.60 .63-.69 .76-.90	.45-.90	.45-.52 .52-.60 .63-.69 .76-.90
Stereo	In track		In track		In track		In track	
Pointing-in trk cross track	±30E ±30E		±30E ±30E		±45E ±45E		±45E ±45E	
Swath width	6x6km	30x30	36 km		8 km		12 km	
Scene size at nadir = in track = cross track =	km^2 36 ? ?	km^2 900 ? ?	km 36 x 36 36 x ? 36 x ?		km 8 x 8 8 x 4,260 8 x 852		km 60 x 60 60 x ? 60 x ?	
Sensor position	GPS		GPS		GPS		GPS	
Sensor attitude	No		No		Star Trackers		3 Star Trackers	
Accuracy with GCP's = w/o GCP's =	Horiz 6m -	Vert 4m -	Horiz 2m -	Vert 3m -	Horiz 2m 12m	Vert 3m 8m	Horiz 2m 12m	Vert 3m 8m

Figure 4: Sensor Information.

Corporation "System"	**EarthWatch** "EarlyBird"	**EarthWatch** "QuickBird"	**Orbital Sciences** "OrbView-1"	**Space Imaging**
Scenes (max)	500/orbit	100/orbit	535/day	process 600/da.
On board recording	Yes 500 scenes	Yes 100 scenes	Yes 250 scenes 32 Gb	Yes 120 Gb
Delivery time - Acquis to User	15 min. - 48 hr.	15 min. - 48 hr.	15 min. - 24 hr.	24 - 48 hr.
Ground Station Sites	EarthWatch owned stations - California, Alaska, Europe		Regional Affiliates	Denver,Alaska, Japan,+Region Affiliates

Figure 5: Communications/Processing Information.

3. EARTHWATCH INCORPORATED

The merger of commercial remote sensing activities of the WorldView and Ball Corporation brought together two distinctively different technical approaches. Combined they provide a formidable constellation of imaging systems to address the breadth of the applications market. EarthWatch Inc. headquarters are located in Longmont, Colorado. It is managed by Dr. Richard Herring, Chief Executive Officer, a Senior Vice President from Ball Corporation; Douglas B. Gerull, President and Chief Operating Officer, the 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 its combination of one, three, four and 15 meter resolutions available from the two satellites orbiting in tandem, it offers the user a wide choice of metric and spectral options. Plans are to launch the three and 15 meter resolution EarlyBird in April 1996 followed by a July 1997 launch of the one and four meter resolution QuickBird. Subsequent satellites will be launched based on market demand, although two of each satellite are now under construction. EarlyBird's two-dimensional CCD staring array cameras are unique and both its panchromatic and multispectral digital images will have the attributes of traditional film image frame cameras. That is, its design is to offer rigid photogrammetric geometry for the high metric accuracies needed by the GIS and mapping community. EarlyBird's multispectral (MS) frames cover an area of 30 by 30 kilometers over which it can image simultaneously 6 by 6 km panchromatic (pan) scenes. The entire MS frame can be covered in stereo by 36 pan scenes. Using photo identified control, EarlyBird is capable of providing an RMS accuracy of six meters horizontally and four meters 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. The MS and pan imagers of QuickBird share a common aperture.
Unlike its competitors, "EarthWatch 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 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, Colorado 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. This 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 assure image quality and utility, as well as speed of delivery.

4. ORBITAL SCIENCES CORPORATION - ORBIMAGE

The Orbital Sciences Corporation (OSC) is the USA leader in light-sat launches, highlighted 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. The first of its imaging systems, "SeaStar" will be launched in mid 1995 to measure daily levels of phytoplankton chlorophyll in the oceans. OSC and ORBIMAGE headquarters are located in Dulles, Virginia. 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 will include a one and two meter resolution panchromatic sensor and an eight meter resolution MS sensor which will share a common aperture. It is scheduled for launch in the Fall of 1997. It features an electro-optical camera that has capability to image scenes 45E off axis in all directions. This flexibility provides an average

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revisit time, for an area of repetitive interest, of 1.8 days at the equator, 1.5 days at ±30E latitudes, and 0.9 day at latitudes of ±60E. The typical scene size is 8 by 8 km, but its collection capabilities are highly flexible. 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 m 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 and sell OrbView imagery to customers in their nation or geographic region of the world. ORBIMAGE will support these distribution centers with capability to produce a variety of standard products such as orthorectified image maps, seamless mosaics, contour maps, digital terrain models, stereopairs, image enhancements, perspective scenes, etc.

5. SPACE IMAGING, INC.

On 15 May 1995 Space Imaging, Inc. opened its headquarters in Thornton, Colorado having relocated from Sunnyvale, California. Formed initially by Lockheed Missiles and Space Co., Space Imaging is now an independent corporation of which Lockheed, E-Systems and Mitsubishi are minority partners. Space Imaging 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. As shown in figure 6, the system has a very expansive field of regard. It 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 to 15 m range. With the addition of ground control points (GCP's) 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!

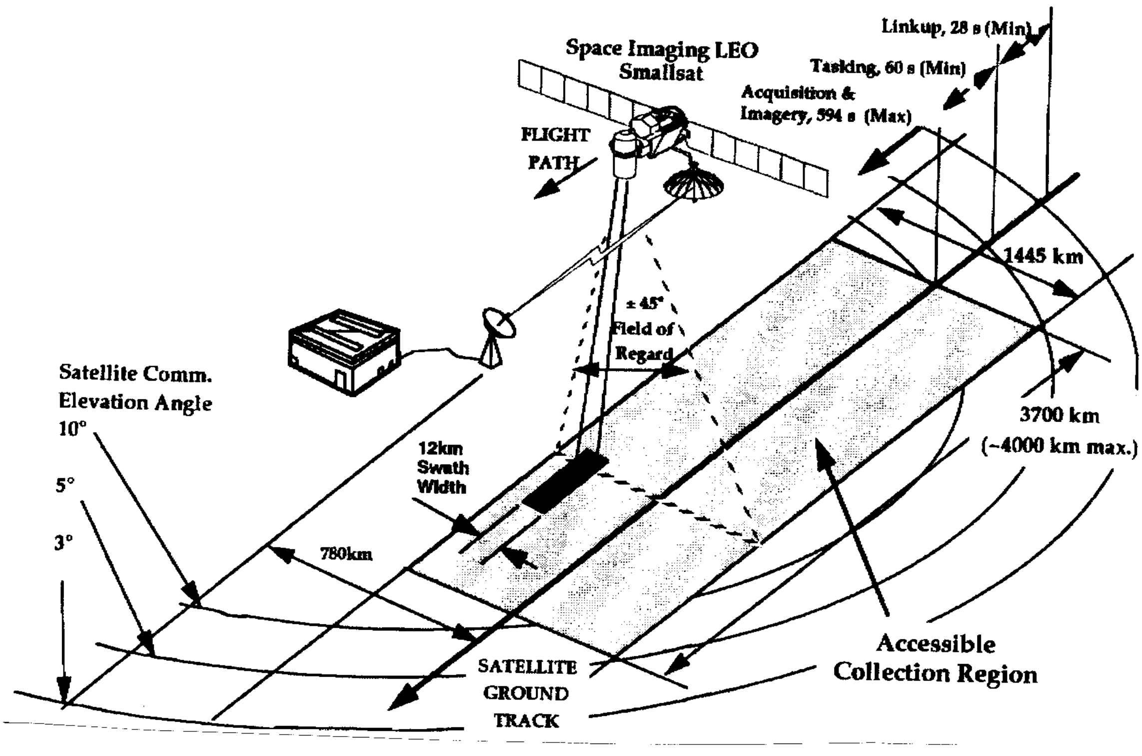

Figure 6: Typical Tasking Scenario*.

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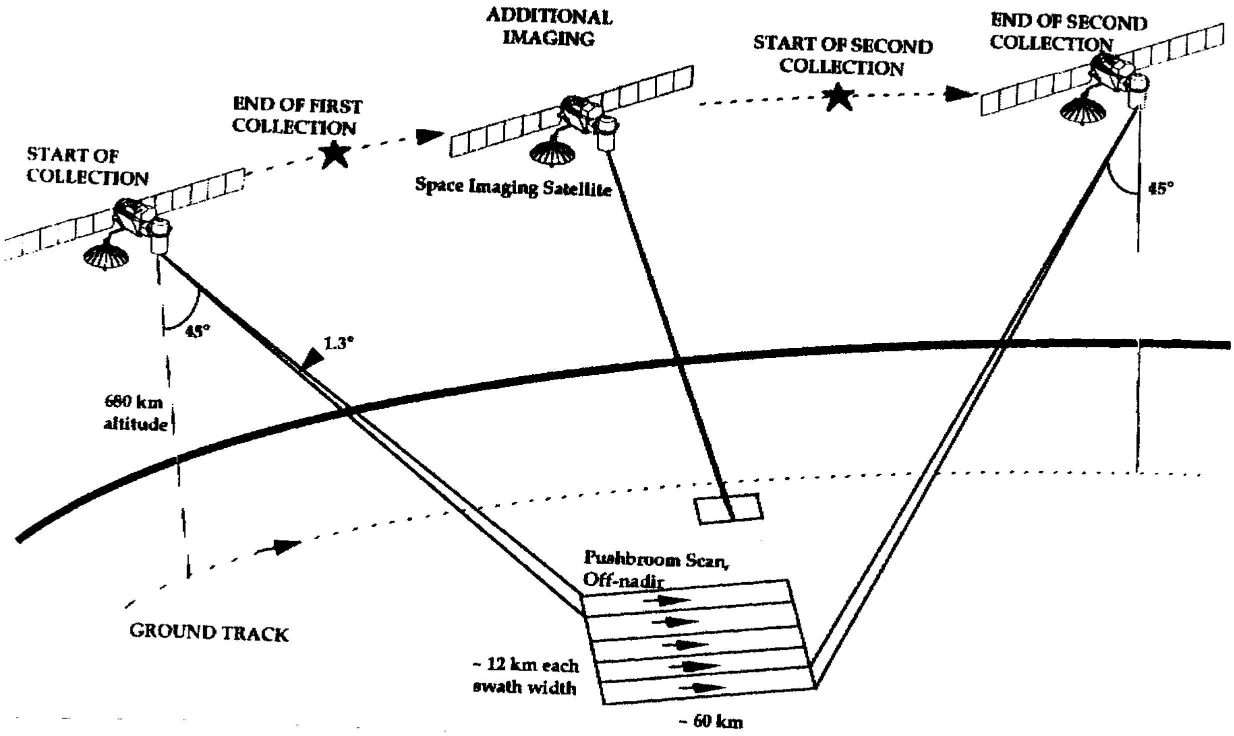

Figure 7: Stereo Collection Operations*.

* Courtesy of Space Imaging™/SM

Uplinks to the satellite contain user requested latitude/longitude bounds, desired bandwidths and tasking (imaging) priorities. Figure 7 shows a typical stereoscopic collection operation. 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 the imagery and its metadata for processing.
Space Imaging, Inc. is establishing a network of regional affiliates. Regional and portable ground stations will task and control image acquisitions. Corresponding regional remote sensing facilities will 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 GCP's (to a selection of map projections) for reconnaissance and monitoring; Precision Geometrically Corrected - rectified with GCP's for high precision orthophotos (up to 2m horizontal accuracy); Orthorectified - precision geometrically corrected including terrain elevation data to support up to 1:2,400 orthophotos; Digital Terrain Matrix (DTM) - elevations generated from stereo pairs; Multispectral - pan-sharpened MS (fused pan and MS) or band ratio images (selective fusing of MS bands); and Image Mosaics - single continuous image scene created from contrast/brightness balancing of multiple overlapping images.

6. SUMMARY CAPABILITY

All of the proposed US 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 plans to launch additional satellites to provide constellation coverage which will increase imaging opportunities for optimal sun angles, repetitive coverage, stereo coverage and timely monitoring of events. The orbits are in general circular, low-earth-orbits (LEO). Orbit altitudes have been influenced by market considerations, such as to optimize 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 blue, green, red bands of the visible and the near infrared band which, in general, replicate the bands of Landsat and SPOT. Each of the systems will rely on 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, thus for example, providing opportunities for optimizing stereo base-height ratios or for acquiring off-track stereo imaging if requested.
As outlined in the above sections, each of the three companies has a different approach for providing imagery and imagery products to users. The main points to be realized are that these companies are offering imagery which is of spatial resolution from one to ten magnitudes higher than is commercially available from current space systems and which is metrically sound and which nominally can be delivered from near-real-time to 48 hours from image acquisition!

7. ISSUES

International acceptance of the concept for high resolution space imaging systems to commercially deliver image data on a daily basis, which heretofore has been the privileged domain of governmental organizations, is a primary issue which will soon be tested.
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, etc. information warrants the risk. Market projections for this industry consistently estimate its growth to $8 billion by the early years of 2000. The bulk of initial sales will likely be to governments, since that is where most world mapping and reconnaissance programs are funded. The commercial GIS market is expected to flourish rapidly, however, because of the cost effective, synoptic and repetitive coverage these systems can provide. Just imagine how the typical 175 km^2 coverage of a single one-meter image over a local municipality can provide it with timely information about the status of its demographics, utility and transportation infrastructures, crop predictions, planning assessments, etc. The value of this timely information should certainly stimulate the need for the acquisition of the image products, software and hardware needed for image exploitation. With this in mind, how will this affect the aerial photography industry? It is anticipated that well over 50% of the imaging provided by this highly fragmented industry will be drawn off by this 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, and stereometric fidelity make them very cost competitive with aerial images. In fact, for square unit of coverage, aerial images are anticipated to be twice as expensive.
Much speculation has risen regarding whether the marketplace for imagery is sufficient to sustain multiple commercial high resolution space systems. Especially since the infrastructure for modelling, enhancing and extracting *spatial information from digital* orbiting systems is currently quite limited in most regions of the world. However, the years of experience from information processing (mostly thematic) of digital remote sensing data using Landsat, SPOT, AVHRR, etc. will assist the transition. A recognized fact is that, in the rush and glamour to utilize outer space, governments have always given the highest priority for funding imagery collection systems and have allocated very limited resources for imagery exploitation systems. As a result many remote sensing images have been archived and never used. These new corporate entities recognize these infrastructure needs. In forming their corporate partnerships and distribution alliances, each of the three US companies is using different strategies, providing many consumer alternatives for value-added images (georegistration, orthorectification, feature enhancement, radiometric intensification, etc.) and value added products

(DTM's, orthophotos, image mosaics, fused MS and pan scenes, etc.). It can be expected that this *total service capability* environment will strongly influence the entire GIS/mapping community to coalesce many of its traditionally fragmented, small (what is 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 a sign of technological, industrial and scientific maturation.
What are the technical challenges to the photogrammetrists and remote sensing specialists posed by these new sources of imagery? Foremost is the all digital processing environment concept. Although hardcopy image products can and will be available, the accuracy, timeliness, and automation benefits to be realized are in the use of softcopy workstations. Tasking strategies to request and obtain desired geometries must be balanced between time of day (sun angle), weather (cloud cover) predictions and the needed image footprint, resolution, and bandwidths. Data extraction software will be needed to accommodate image obliquities and off-nadir geometries. Fully automated stereomodel reconstructions and commensurate stereo operator retraining may be required. Photointerpretation becomes significantly easier with the availability of high resolution images. However, the variety of possibilities to improve and eventually automate feature extractions will require innovative multiband data fusion and image enhancement techniques which all digital environments can provide.
The challenges are non-trivial but certainly are achievable. The full gamut of imagery forms, from uncorrected pixels with orbital ephemeris data to fully preprocessed standard imagery products data, is being offered by these companies. It is up to the photogrammetric and remote sensing specialists to develop the value added processing for the myriad of applications, both traditional and new, which these high resolution digital images can satisfy.

8. SUMMARY

The three US companies have made major financial commitments to launch their high resolution systems before the end of 1997. They are aggressively forming their corporate international infrastructures. The information age is helping to focus our disciplines through the emergence of this new industry. And the photogrammetric and remote sensing technologic and scientific community will be forever impacted by this commercially new technological availability. We must be introspective and address new strategies for developing/selecting the best tools for satisfying the applications which need our support, be they geographic, environmental, social, national interests, or scientific. The optical earth observation industry is maturing. We commend these companies for taking on the risks of commercialization and we thank them for their confidence in our research efforts to support them.

9. ACKNOWLEDGEMENTS

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